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PROLONGED HEAVY VEHICLE DRIVING PERFORMANCE: EFFECTS OF UNPREDICTABLE SHIFT ONSET AND DURATION AND CONVOY vs. INDEPENDENT DRIVING CONDITIONS

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BASIC RESEARCH

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Truck driver safety was studied under conditions of prolonged normal driving, prolonged continuous convoy driving, and continuous convoy driving under conditions of task uncertainty. In all experiments drivers were required to drive an experimental truck for four consecutive days. Dependent variables were driver performance, self ratings, and endocrine changes. Apart from changes over time, where possible the effects of age and time of work period onset were determined.

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Symptoms of fatigue were most typical of the end of the driving shift, becoming evident from about the 9th hour of driving, and were particularly characteristic of older drivers on a shift finishing at 02.30 hours. Nevertheless the requirement to drive 11 hours per day for 4 consecutive days did not lead to conspicuous deterioration in driving performance under normal driving conditions. Even under continuous convoy driving such prolonged work did not produce impairment but elicited compensatory adjustments toward the end of the late shift. Finally, task uncertainty was not found to induce earlier fatigue. Drivers appeared to adjust to this condition by covertly anticipating a demand in excess of actual requirement.

A behavioural analysis of the driving task was proposed and among other features its implications for driver fatigue and traffic accidents were discussed.

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The review which follows provides an overview of work carried out under Grant Number DAERO-78-G-006. This work is presented in full in a series of reports and papers which are itemised below.

1. Effects on HGV drivers of different work demands. In Human Factors in Transport Research, Vol. 1 (Edited by D. J. Oborne and J. A. Levis), London: Academic Press, 1980.

2. Determinants of time headway adopted by truck drivers. Ergonomics, 1981, 24, 6, 463-474.

3. Unobtrusive technique for continuous recording of automobile headway. Perceptual and Motor Skills, 1980, 51, 293-294.

4. Prolonged driving in convoy: The truck driver's experience. Paper provisionally accepted for publication in Accident Analysis and Prevention, 1983.

5. Endocrine stress responses of drivers in a 'real-life' heavy-goods vehicle driving task. Psychoneuroendocrinology, 1979, 4, 107-115.

6. Effects of prolonged driving on time headway adopted by HGV drivers. Army Research Institute Research Note 83-33.

7. Determinants of time headway adopted by truck drivers: A reassessment. Paper submitted for publication in Ergonomics, 1983.

8. Truck driving performance with unpredictable shift onset and duration: A preliminary study. Paper submitted for publication in Human Factors, 1983, under the title "Self pacing and truck driving performance: A preliminary study."

9. The CAR and driving: A behavioural conceptualisation. Paper submitted for publication in Ergonomics, 1983.

10. Time headway in different vehicle-following manoeuvres. Perceptual and Motor Skills, 1980, 50, 1057-1058.

PROLONGED HEAVY VEHICLE DRIVING PERFORMANCE: EFFECTS OF UNPREDICTABLE SHIFT ONSET AND DURATION AND CONVOY VS. INDEPENDENT DRIVING CONDITIONS

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REVIEW OF EXPERIMENTS

The main aim of this study was to explore the relationship between prolonged driving and performance safety under a variety of conditions. Three field experiments were carried out, the first focusing on normal driving conditions, the second on continuous convoy driving, and the third on continuous convoy driving under conditions of unpredictable onset and duration of driving shift. All three studies used the same experimental heavy goods vehicle, employed professional truck drivers who were required to drive while being observed for 4 consecutive days, and examined effects in three types of dependent variables: driving performance, drivers' self ratings, and endocrine changes. Apart from changes over time, where possible the effects of age and time of work period onset were also determined.

The Driving Task

It is generally assumed that after a prolonged period of driving, performance will deteriorate and attempts to continue on driving may be associated with an increased likelihood of accident. This line of reasoning is implicit in road safety legislation which limits the number of hours a truck driver may drive such as EEC Regulation No. 543169 which restricts truck drivers to an 8-hour driving period. However, with few exceptions an unambiguous relationship between hours of driving and increased risk of accident has not been demonstrated experimentally (Fuller, 1980a--see Appendix A).

For this reason Experiments 1 and 2 of this study observed drivers driving for 11 hours per day on 4 consecutive days. The essential difference between these two experiments was that the second involved continuous convoy driving, a task which is more demanding on the driver since normal driving involves only about 2.5% of time actually following another vehicle. Convoy driving is frequently a feature of manoeuvres of military vehicles but is also growing in civilian police operations and is characteristic, although unintentional, of much high density urban and interurban traffic. Both experiments employed two different start times for driving, either 09.00 hours or 15.00 hours, finishing respectively at 20.30 hours and 02.30 hours.

Experiment 3 sought to explore the relationship between prolonged driving and performance safety from a different perspective. In the normal work situation the worker knows for how long he must work and usually how hard he must work--he is thus able to pace himself so as to avoid undesirable fatigue effects. But what happens if, because of unpredictable demands, a driver simply cannot manage his effort in this way? To begin to answer this question a condition was created in which advance information was withheld from drivers about the onset time for driving, duration of driving periods, and time of completion of the day's work.

Driving Performance

Driving performance was measured in terms of mean hourly or half-hourly time headway and its variability and the distribution over time of relatively short (<1.0s) or relatively long (≥2.5s) headways. Time headway may be defined as the time it takes a following vehicle to reach a leading vehicle if the latter stops dead. It was chosen because:

1. It may be interpreted unambiguously in terms of accident riskiness (Lehman & Fox, 1967), at least under otherwise stable conditions;

2. Adopting too short a headway appears to be a major contributing factor in rear-end collisions (Fuller, 1981--see Appendix B); and

3. It constitutes a convenient way of representing the interaction between a driver, his vehicle, and significant features of the traffic environment, particularly in a convoy situation.

Time headway was measured with a closed-circuit TV system which used the calibrated displacement of the superimposed images from two TV cameras mounted on the experimental vehicle (Fuller, Holahan, & Bolger, 1980--see Appendix C). This system was developed with the following features:

1. It was powered by the vehicle's own electrical power output;

2. It was unobtrusive;

3. It did not involve any connection with a lead vehicle; and

4. If desired, the driver could be kept completely unaware that his following performance was being monitored.

Self Ratings

At suitable breaks during driving sessions, drivers rated aspects of their performance and feelings of fatigue for the preceding period on a series of 5-point scales (for details, see Fuller, 1978). They also rated their willingness to continue on driving. These experiential measures were taken because it is argued they may be construed as part of an adaptive feedback system signaling to the driver stress, strain, and ultimately impending breakdown (Fuller, 1983b--see Appendix D).

Endocrine Changes

Although normal diurnal endocrine profiles for particular gender/age combinations lamentably simply do not yet exist, pre-post driving changes in a number of hormones were assayed and compared with changes recorded on a non-driving day. For Experiment 1, serum levels of Cortisol, Testosterone, and Prolactin were examined but this last was not included in Experiments 2 and 3. In all studies, urine levels of Adrenalin and Noradrenalin were measured, samples being collected over each half of the driving day (for details, see Cullen, Fuller, & Dolphin, 1979, Appendix E). These endocrine variables were included because certain changes reflect the mobilisation of biological coping mechanisms (Appley & Trumbull, 1967) and these may precede or complement any noticeable changes in either performance or feelings.

General Results

Experiment 1--Normal Driving. Details of the results of this experiment are presented in Fuller (1980b) (see Research Note 83-33). For both the early and late driving shift, time-related changes in headway did not offer any convincing evidence of task-induced changes in riskiness. On the early shift relatively close following was associated with periods of rural open road driving and on the late shift with periods following the experimental lead vehicle which had been introduced to increase the frequency of following episodes. It was suggested that drivers were adjusting headway in response to their judgment of the probability of sudden velocity decreases in the lead vehicle, adopting a short time headway when velocity decreases were unlikely and vice versa.

A significant correlation between time headway and time headway variability was noted in this study and attributed to the following:

- With short headways, deceleration by the lead vehicle requires adjustment by the following driver to avoid high risk following situations. With long headways such adjustments are relatively unnecessary. Thus a lower variability in headway under close following conditions is a safe driving requirement.

- Shorter headways make detection of headway change easier and thus make adjustment easier, so reducing variability.

- Drivers adopt short headways when there appears to be low probability of speed variation in the lead vehicle. Relatively constant lead vehicle velocity facilitates maintenance of a stable following interval.

Consistent with the apparent absence of fatigue effects in the performance results, for the majority of days (58%) drivers reported that the 11-hour driving period was "just right" and on only 25% of occasions did they report it to be too long, by about 1.2 hours on average. Nevertheless, on the late shift drivers progressively became more drowsy and older drivers rated themselves as more exhausted in the latter half of the shift, more drowsy on the last 2 days, and more drowsy overall. They would also have preferred to have stopped driving earlier than the younger drivers. Although not reflected in driving performance, these symptoms of drowsiness and exhaustion in the older drivers were mirrored in the Cortisol response pattern in which the expected decrease in level over time did not occur for the old group (Cullen et al., 1979--see Appendix E).

Experiment 2--Convoy Driving. The results of this experiment are presented in four separate papers (Fuller, 1980a; 1981; 1983a; 1983b--respectively Appendixes A, B, F, and D). The first two include comparisons between convoy and normal driving, the third concentrates on the distribution over time of very short and very long headways, and the fourth is concerned in particular with the truck driver's experience.

A relatively long mean time headway and greater headway variability were associated with the first hour of driving (particularly on day 1) and with the late shift. Similarly, from the frequency distribution of short and long headways over time it was found that drivers were about three times more likely to follow closely (TH < 1.0s) during the early shift compared with the late shift, that long headways (TH ≥ 2.5s) were particularly characteristic of the first hour but also that long headways tended to occur in periods just before each main break from driving (periods 11 and 22). Furthermore, when closing on the vehicle in front, it was found that braking tended to occur earlier under the following conditions:

1. on the late shift;

2. during the first hour of driving; and

3. during the last hour of driving, particularly for older drivers on the late shift.

In contrast to the results for normal driving conditions, drivers in convoy stated that they felt like stopping earlier on 38% of occasions and declared that the 11-hour period was "just right" on only 23% of days. The greatest reluctance to drive on was expressed by older drivers on the late shift (on average they would like to have stopped over an hour earlier) and consistent with this was their relatively elevated Cortisol level at the end of the shift. In general there was a decrease in motivation typical of the end of the late shift, a period which was also characterised by

1. a slight deterioration in rated performance,
2. increases in drowsiness and exhaustion,
3. more daydreaming in younger drivers, and
4. a greater frequency of hallucinations.

Perhaps the most important observation in this study is that these symptoms of deterioration as experienced by drivers were not represented by correlated increases in the riskiness of their vehicle-following performance. Indeed, by objective standards their performance became <u>less</u> risky under these circumstances. It was suggested therefore that drivers increased time headway as a safety-oriented response to experienced increases in task difficulty. Thus headway was increased at night when there was greater difficulty of detecting and predicting sudden velocity decreases in the lead vehicle, was increased at the start of the day when drivers were adjusting to the convoy close-following requirement, and was similarly increased when their capability deteriorated because of drowsiness, fatigue, daydreaming, and hallucinations.

<u>Experiment 3--Convoy Driving with Unpredictable Shift Onset and Duration</u>. This experiment is reported in full in Fuller, Higgins, Tierney, and West (1983) (see Appendix G). No effect of the withholding of advance information about major task parameters was found on mean half-hourly time headway or time headway variability or on the distribution of relatively short and long time headways. However, consistent with Experiment 2, long time headway and its variability were associated with the beginning and end of the driving day, the end-of-day effect being particularly characteristic of the longer schedules involving 8 or 9 hours of driving and a driving span of up to 11 hours. In like vein the proportion of long headways was relatively high for the first

half hour and for the end of the 9-hour run. Also consistent with Experiment 2, but not so evident, were observations of slight increases in drowsiness, exhaustion, and daydreaming over blocks of driving.

The endocrine results, however, revealed no evidence of biological strain over time whether information about the driving task was withheld or not. In the uninformed condition subjects clearly set up their own expectations and in general these more than encompassed the requirements actually placed on them. If anything, the measure of task uncertainty might have prevented the distinct tendency seen in the informed group to engage in daydreaming. For this latter group time also passed more slowly on the first 2 days and they were also more likely to increase awareness of the passage of time. Other differences related to the information variable were that the informed group:

1. had more sleep,

2. had slightly better sleep quality and were less drowsy or bored before driving, and

3. rated themselves as slightly more courteous and better at decision making.

Again, the interpretation of these results focused on the concept of drivers adjusting headway to take account of experienced increases in difficulty, rather than reflecting such increases in difficulty in performance deterioration.

A CONCEPTUALISATION OF DRIVER BEHAVIOUR

The pattern of results of the three studies described above may be interpreted in relation to a model of driver behaviour developed by the author and described in full in Fuller (1983c--see Appendix H). This model, which is based on an application of behavioural principles to the driving task, is outlined briefly below and is followed by a discussion which relates the obtained experimental results to the model's basic features.

The Threat-Avoidance Model

Unlike a motor-boat journey across a deep, still lake, which requires selection of a suitable heading and desired speed and little else, journeys by road require frequent adjustments to avoid potential aversive stimuli such as colliding with other vehicles and obstructions on the road, driving off the roadway, or taking the wrong route.

Figure 1 describes an abstract representation of possible outcomes when a driver is faced with a potential aversive stimulus or threat (box b). The threat stimulus may be preceded by some kind of sign or discriminative stimulus (box a) or by no discriminative stimulus (box h). In the model a discriminative stimulus for a threat is represented as arising out of the integration (small circle u) of two types of information, the driver's speed and intended path ahead of his vehicle (circle s) and his current (and immediately projected) capability (circle t).

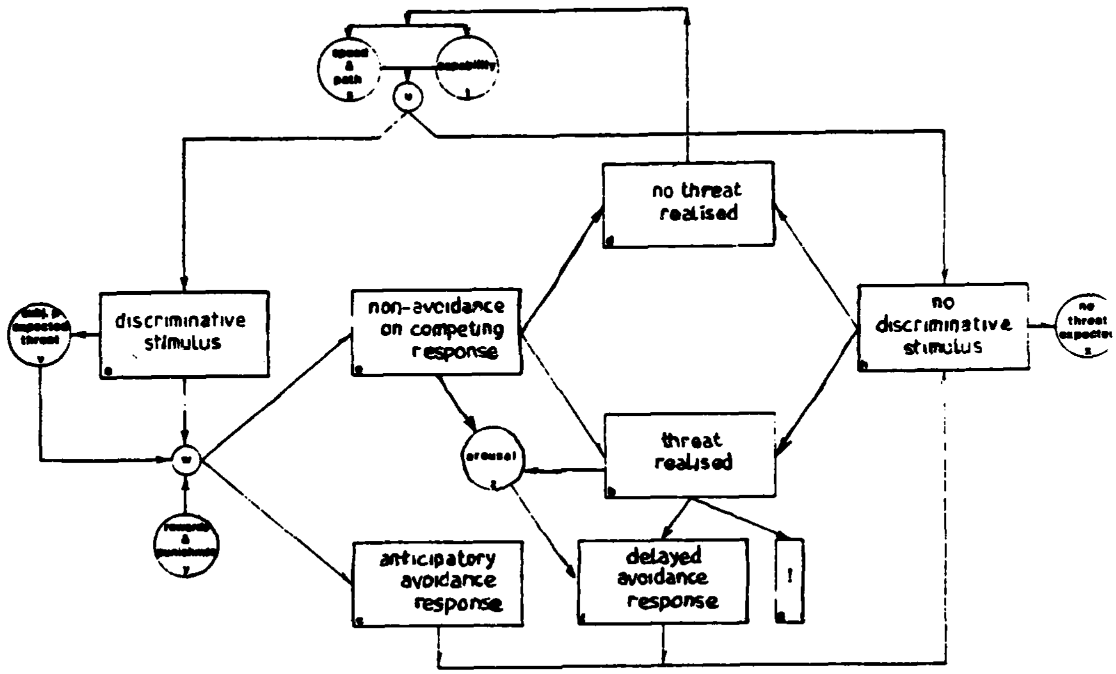

Figure 1. Threat-avoidance model of driver behaviour.

Given that a discriminative stimulus for a threat occurs, the response of the driver may be either an anticipatory avoidance response (box c), which when emitted effectively "cancels out" the threat (box h → box d), or a non-avoidance or competing response (box e). Which of these occurs depends in part on the driver's subjective probability for the expected threat (circle v) and in part on the rewards and punishments for alternative responses (circle y). If no avoidance response is made and this is followed by no threat occurring (box e → box d), then the driver may continue on his journey undisturbed. However, if a threat is realised (box b), the driver has to make a delayed avoidance response (box f) or suffer an accident (box g).

It may be noted that the model allows for aversive increases in arousal (circle z) (corresponding to feelings of fear, anxiety, tension, or risk) to motivate delayed avoidance responses, either because the driver is aware he should have made an avoidance response but has not done so (box e → circle z → box f) or because a threat has been realised and requires some avoidance action (box b → circle z → box f).

If a threat is realised (i.e., a potential aversive stimulus actually occurs) but there is no discriminative stimulus for it (box h → box b), then no anticipatory avoidance response can be made, only a delayed avoidance response. It is self-evident that, in general, the greater the delay before an avoidance response is made the less time there is available to select and execute effectively an avoidance response and indeed the fewer are the options available to the driver. Thus increased delay in avoidance responding is generally associated with increased probability of accident.

One further general point is that the model incorporates situations where avoidance responses have been made but are inappropriate or ineffective, despite the driver's expectation that they will be successful (box c or f → box h and circle x → box b). Such situations would be particularly critical for safety where the failed response was already a delayed avoidance response, leaving little if any time to attempt a modified avoidance response.

Translating the core of this abstract series of events into a hypothetical driving situation, imagine a driver on a narrow lane approaching a blind corner. A potential aversive stimulus or threat might be an unseen vehicle approaching from the opposite direction (box b). The discriminative stimulus for this (box a) might arise out of the combined effects of the driver's recognition of the blind corner in his intended path (circle s), his current speed (circle s), and perhaps awareness of his current capability to respond safely should a hazard arise (circle t).

Experience of road situations similar to the one currently perceived (and indeed perhaps of this particular part of this particular road) will dispose the driver to have an expectation of the likelihood of meeting an oncoming car (circle v) and this subjective probability along with rewards and punishments for alternative responses (circle y) will determine whether he makes an anticipatory avoidance response (box c) or not (box e).

A typical anticipatory avoidance response in the situation under consideration might simply be that of reducing speed, so as to be able to cope safely with an oncoming vehicle should it arise, and fixating the actual corner to facilitate detection of any oncoming vehicle. If speed reduction has been adequate, then the appearance of an oncoming vehicle would not pose any threat and the driver could continue safely to the next section of road (box c → box h → box d).

However, let us assume that the driver is on the verge of being late for an important appointment. In that instance slowing of his vehicle (the anticipatory avoidance response) could be punishing by making him late (circle y) and so a nonavoidance response of maintaining speed (box e) might be made. If no car is met on the bend (box d), then the driver will not have been delayed, his nonavoidance response will have been reinforced and he might, for the present at least, continue on unscathed. On the other hand, should an oncoming car materialise (box b), a delayed avoidance response of sharp braking and perhaps severe swerving would be required (box f). If an avoidance response was delayed too long, however, a collision (box g) would ensue.

Although the essence of the model is here exemplified in only one particular kind of road hazard, the general features of the model may be found in any potentially aversive or threatening situation in driving such as overtaking, accepting a gap in a traffic stream, negotiating a road junction, coping with a slippery road surface, and following another vehicle.

Threat Avoidance in Prolonged Truck Driving

The pattern of results found in the three field experiments summarised earlier may be construed as one of adjustment to preserve safety in situations in which the possibility of potential aversive stimuli was increased. This adjustment was observed partly in terms of time headway increases.

In Experiment 1 it was argued that increased headways were associated with situations in which there was an increased probability of sudden velocity decrease in the leading vehicle. In Experiment 2 (convoy driving) increased headways were associated with the first hour of driving, the end of each shift half, and with the late shift, all periods during which it was suggested drivers would have experienced some increase in task difficulty or danger. And in Experiment 3, increased time headway was again associated with the beginning and end of the driving day, particularly on longer driving schedules. This interpretation of end-of-shift effects, especially for older drivers, was bolstered by evidence indicative of decreased motivation, increased ratings of exhaustion, drowsiness, hallucinations and daydreams, and relative physiological strain (old drivers only).

A further form of adjustment to supposed increases in potential aversive stimuli or threat was also found in drivers' braking performance in Experiment 2. In this experiment, earlier braking when closing on the leading vehicle was found under similar conditions to those characterised by increased time headway.

In terms of the threat-avoidance model outlined above, these observed increases in time headway and earlier braking may be construed as anticipatory avoidance responses to discriminative stimuli signalling increased likelihood of threat (refer to Figure 1). In some instances the predominant factor underlying the discriminative stimulus appears to have been the speed and path of the vehicle (i.e., where this was associated with increased probability of the threat of sudden lead vehicle deceleration in Experiment 1). In other instances it appears to have been impairment in driver capability (i.e., decreased visibility in darkness in Experiment 2, lack of practice in Experiments 2 and 3, and states of drowsiness or exhaustion in both experiments). In sum, it may be stated simply that increases in the probability of threat, whether arising externally (e.g., road hazards) or internally (e.g., drowsiness) were met with anticipatory avoidance responses which effectively removed the threat.

IMPLICATIONS

The results of the three experiments described in this report and the conceptualisation of them summarised above contain within them a number of implications both operational and methodological, as well as implications for our conceptualisation of the relationship between fatigue and performance safety.

Operational Implications

1. Prolonged Driving. Symptoms of fatigue, in terms of increased headways, decreased motivation, and self-reports of increased drowsiness and exhaustion were most typical of the end of the driving shift, becoming evident from about the ninth hour of driving, and were particularly characteristic of older drivers on the later shift (finishing at 02.30 hours). These observations are at least consistent with the results of a statistical analysis by Miller and Mackie (1980) which noted that an accident involving a dozing driver was about seven times more likely to occur in one of the early morning hours than in one of the other hours of the day. They also found in a field experiment on truck drivers operating alone that fatigue effects became evident after about 8 hours of driving when the schedule was regular. Eight or 9 hours of driving, then, appears to represent a threshold for fatigue effects in prolonged driving.

2. Convoy Driving Requirements. Clearly there are limits to the conditions in which adjustments (avoidance or escape responses) can readily be made to prevent marked increases in driving riskiness (e.g., at the point of starting a long slide or skid on ice or after driving for a particularly prolonged period). Nevertheless, the evidence found here for truck drivers is that the requirement to drive 11 hours per day for 4 consecutive days with only minimal breaks does not lead to conspicuous deterioration in driving performance under normal driving conditions (see Brown et al. (1967) for a similar conclusion regarding 12 hours' car driving). Even under continuous convoy driving, such prolonged work does not produce impairment but elicits compensatory adjustments toward the end of the late shift.

Thus, sufficient flexibility should be allowed for drivers on relatively demanding operations to enable individual adjustments to be made. Specifically in convoy driving:

1. Drivers should not be constrained to very close following on

    a. the early part of a journey,
    b. when they experience symptoms of fatigue,
    c. when driving in darkness, and
    d. when on a shift which extends into the early hours of the morning.

2. Drivers of different ages (and driving experience) may need to make different kinds of adjustment to the demands of prolonged convoy work. In particular, older drivers were found to be more cautious in their braking performance at the start of the 11-hour convoy and braked earlier in the last hour of driving. This age difference presumably reflects a difference in need to make adjustments rather than a difference in preferred risk level, and it is suggested that this need is in response to a perceived weakness in performance capability or competence.

3. Unpredictable Shift Onset and Duration. Although Miller and Mackie (1980) have found evidence indicating that task irregularity may induce earlier fatigue in long-distance truck and bus drivers, task unpredictability as manipulated in the third experiment described here had no such effect. When basic advance information about driving task parameters was withheld from drivers,

they appeared to adjust by covertly anticipating a demand in excess of actual requirement. The meaning of this result, however, should not be taken to imply that drivers need not be warned in advance of actual or likely requirements. Consistent underestimation by a driver of what he is going to have to do, particularly over a prolonged period, may increase his vulnerability to performance decrement and physiological and psychological stress and strain. Nevertheless, for the moment the evidence is not yet available to enable a final assessment of that contention.

4. Driver Selection. It is self-evident that the risk level displayed by drivers will to some extent vary depending on the goal of a particular driving task and the constraints operating upon it. Over and above this, however, it may be that individuals reliably differ in their disposition to make delayed rather than anticipatory avoidance responses (see Fuller, 1983c (Appendix H and Zwahlen, 1973) and such individual differences may be highly relevant to the selection of personnel for particular kinds of operation.

Methodological Implications

1. Time Headway as a Measure of Driver Performance.

(a) Determining a driver's mean time headway for each hour or half hour of operation does not enable detection of brief, transient changes which may be of crucial importance. The distribution of very short (<1.0s) and very long (≤2.5s) headways may constitute a more sensitive measure of headway performance (for example, see Evans & Wasielewski, 1982).

(b) The relationship between time headway and risk is not as unambiguous as originally suggested (e.g., Lehman & Fox, 1967). Short time headway appears to be characteristic of situations in which the probability of a lead vehicle velocity decrease is relatively low. Consequently, assuming that the probability is not underestimated for whatever reason, it may not simply be inferred that the shorter headway is necessarily riskier. Furthermore, the riskiness of short headways must in part be determined by the driver's momentary capability.

Regarding this relationship between time headway and risk, if a long headway is associated with situations in which the probability of a lead vehicle velocity decrease is relatively high (the corollary to the above), then we should expect increased headways when drivers perceive any of the following ahead of them: an obstruction, junction, pedestrian crossing, bend, bridge, ascent, descent, and deterioration in road surface or visibility.

(c) Different types of following manoeuvre are associated with different time headway values (Fuller, 1980c--see Appendix I). They may also be differentially sensitive to the effects of prolonged driving and other kinds of potential stressor.

(d) Where drivers are instructed to adopt a headway which is short enough to discourage other vehicles from intervening, this is on average almost 0.5s less than the recommended 2.0s minimum and one 1.0s less than the headway selected under free driving conditions. Thus, convoy headways of this order appear to demand a level of performance in excess of what would normally be maintained on a voluntary basis.

2. Generalisation. It is perhaps salutary to be reminded of the problems of generalising from experimental field studies of the sort which form the basis of this work. Trucks may differ on a large number of operational characteristics and similarly there is a vast array of dimensions along which drivers, haulage tasks, and road environments may vary. The studies reported here all employed only one type of truck and operated on a restricted range of road conditions, work schedules, and driver characteristics. Furthermore, the exploration of convoy driving was limited to analysis of the second driver in a two-vehicle convoy. This driver's performance may have been different if a third convoy vehicle had been introduced behind the experimental vehicle, and indeed it may well be the case that different positions within a convoy of vehicles are associated with different task requirements and perhaps ultimately different stresses.

Conceptualisation of the Relationship Between Prolonged Work and Performance Safety

As suggested in the introduction to this review, there is a general assumption that performance deterioration and increased accident likelihood may result from prolonged periods of work. This assumption is implicit in legislation which, on grounds of safety, limits maximum hours of work and is also implicit in the design of much "fatigue" research (e.g., Brown et al., 1967; Miller & Mackie, 1980), including that of the author. Performance safety in prolonged work is conceived as being rather like a clockwork motor which, when fully wound up, as at the start of a working day, operates continuously and smoothly at a high level but after a period of time winds down, operates at a lower level, and may even become erratic before eventually stopping altogether. This concept may be valid for certain aspects of performance such as speed, strength, or reliability of response. But the work reviewed here casts doubt on its validity in relation to response safety. This is because, on the evidence discussed earlier, where the effects of prolonged work threaten the maintenance of safety, drivers appear to make adjustments so as to preserve that safety. This behaviour is clearly illustrated in vehicle following where drivers compensate for perceived increases in the likelihood of potential aversive events by increasing time headway.

It is suggested in this review that the maintenance of performance safety in the face of impaired capability (due perhaps to prolonged work) depends in part on the ability and opportunity of the worker to make compensatory adjustments. Decrements in safety arise where such adjustments cannot be made (e.g., where compensatory or avoidance responses are beyond the capability of the individual or he is in some way prevented from making them), where the individual is not motivated to make adjustments (e.g., where compensatory responses are punished and/or competing responses rewarded), or where the individual makes inappropriate adjustments.

With this perspective it may be seen that any factor which shifts control from the driver to some external agent, whether it be legislation, the pace of the traffic stream, or externally manipulated rewards and punishments, may have a deleterious effect on the driver's adjustment process. Thus, for example, legislation to restrict hours of work to avoid a supposed fatigue-induced decline in safety may be counterproductive because it removes a major dimension of compensatory adjustment from the fatigued driver, namely that of taking more time to achieve the intended journey goal. In order to reach a particular destination within an 8-hour deadline, a fatigued driver may have to drive <u>more quickly</u> toward the end of his shift, precisely at the time when compensatory adjustments might dictate a <u>reduced</u> speed to maintain safety.

In conclusion it may be suggested that improvements in safety levels in prolonged work by experienced, skilled operators might be achieved by:

1. Promoting sensitivity to changes in capability and, more generally, factors which inhibit detection of discriminative stimuli for potential aversive events;

2. Providing opportunities for safe adjustments (i.e., anticipatory avoidance responses). Where change in speed of operation provides an appropriate means of such adjustment, the incorporation of <u>self-pacing</u> in job design clearly achieves this;

3. Enhancing motivation for safe adjustments by rewarding anticipatory avoidance behaviour rather than punishing it and punishing competing responses rather than rewarding them.

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APPENDIX A

EFFECTS ON HGV DRIVERS OF DIFFERENT WORK DEMANDS

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ABSTRACT

This paper reports the results of two recent field experiments on the effects of prolonged driving on performance and safety in heavy goods vehicle drivers. Both studies followed exactly the same experimental design except that in one drivers drove an independent vehicle and in the other drove continuously in a two vehicle convoy. In each experiment, 12 professional HGV drivers drove an instrumented 7-ton Bedford rigid van-type truck for 11 hours on each of four consecutive days over a preselected route of 300 miles, repeated on each day. Drivers were assigned to one of two age groups and within each group allocated at random to one of two driving shifts which started at either 09.00 hrs or 15.00 hrs. Subjects' driving performance was measured in terms of time headway adopted in following situations. Results throw considerable doubt on the notion that prolonged driving is necessarily unsafe and question the assumption that fatigue effects follow a simple incremental progression.

INTRODUCTION

If a truck driver, or for that matter any driver, drives continuously for a prolonged period it is generally assumed that at some point his performance will deteriorate. Furthermore it is also often assumed that attempts to continue driving beyond that point may be associated with an increased likelihood of accident. This line of reasoning is implicit in road safety legislation which limits the number of hours a heavy goods vehicle driver may drive either over a continuous period of time, or within a specified period of time such as 24 hours. One example of such legislation is EEC Regulation No. 543169 which, amongst other things, restricts HGV drivers to an eight hour driving day.

Whether or not eight hours or indeed any other particular period of driving is a meaningful value from the safety point of view is however a moot point and there is a distinct paucity of research directed at the issue. Certainly some statistical estimates of accident probabilities have revealed that real accident frequencies can be greater than expected after prolonged periods of driving under certain conditions (e.g., Harris et al., 1972) and in the U.K., introduction of a maximum number of permitted hours driving per day of 10 hours in 1970 was associated with a decline in the number of accidents involving HGVs. But despite these suggestive observations, with few exceptions (e.g., Brown et al., 1970) an unambiguous relationship between hours of driving and increased risk of accident has not been demonstrated experimentally.

There are several reasons why this may be the case. One reason may be that under the eye of the experimenter the driver is motivated to perform more effectively than under normal working conditions and is thus able to cope with experimentally contrived and necessarily temporary stresses. A second reason may simply be that experimenters shun the idea of designing experiments on the relationship between prolonged HGV driving and accident riskiness because of the enormous sampling problem involved. This problem stems from the fact that only in the grossest sense could one assume that there is only one kind of performance involved in truck driving. Apart from the vast number of operational dimensions along which trucks may vary there is a similar complexity of dimensions along which the driver, the haulage task and the road environment may vary as well. Thus there are virtually insuperable problems of generalisation associated with any particular study.

Notwithstanding such problems two experimental studies were designed to attempt to evaluate directly the relationship between prolonged driving and performance safety by manipulating hours of driving as an independent variable and using the hourly mean time headway adopted by the driver as the criterion of performance safety. Time headway may be defined as the time it takes a following vehicle to reach a leading vehicle if the latter stops dead. This measure of performance was selected because for the following vehicle it is one way of representing the total interaction between the driver, his vehicle and the driving environment. More directly from the viewpoint of performance impairment, short time headways are argued to be fairly readily interpretable in terms of accident riskiness (Lehman and Fox, 1967).

METHOD

The two experiments were designed and carried out in as identical a manner as possible with the one major difference that in the first drivers were required to drive for prolonged periods in a more-or-less normal driving environment whereas in the second they were required to drive continuously in a two-vehicle convoy. The first study was in two parts, an original experiment and a part replication.

Independent variables were hours of driving, days of driving, time of shift onset and age of driver. The main dependent variable was driving performance measured in terms of mean hourly time headway adopted in vehicle following situations.

Subjects in each experiment were respectively 18 and 12 volunteer professional HGV drivers, each paid 77-80 pounds for participating. They were required to drive an instrumented 7-ton Bedford rigid van-type truck for 11 hrs from either 09.00 hrs to 20.30 hrs or from 15.00 hrs to 02.30 hrs on each of four consecutive days over a preselected route of approximately 300 miles. Driving was continuous except for a 30 min. meal break after 5.5 hrs and a 10 min. break during each 5.5 hr period. Time headway for all following episodes with the exception of slow moving (<5 m.p.h.) traffic was continuously monitored and recorded using a closed circuit television system described in detail in Fuller et al. (1978). Other dependent variables recorded were subjects' self ratings of performance, fatigue and motivation in addition to changes in serum and urine levels of a number of endocrine hormones but space does not permit results for these variables to be presented here.

Two different age groups of subjects were selected with mean ages as follows: Experiment 1, Part 1--28.8 yrs (sd 2.9) and 41.3 yrs. (sd 4.1), Part 2--25.3 yrs (sd 5.0) and 43.6 yrs (sd 13.3); Experiment 2--22.7 yrs (sd 1.0) and 33.5 yrs (sd 4.7). Subjects in each age group were allocated at random to one of the two shift onset times. The part replication of Experiment 1 involved the later shift only and was added because of the low incidence of naturally occurring following episodes in the original late shift. In the replication additional following was contrived by the use of a second vehicle which intercepted the experimental HGV at random points along the scheduled route from the fourth hour on.

For the two-vehicle convoy condition which characterised Experiment 2, Ss were required to follow a 15 cwt. VW van so as to prevent vehicles intervening between them and the leading vehicle except in the interests of preserving safety. The leading vehicle was driven by three drivers and each day's driving was divided into four equal periods with drivers allocated at random to each period except for the one constraint that no driver was allowed to drive for more than two periods consecutively.

RESULTS

Results for the first part of Experiment 1 have been reported in detail elsewhere (Fuller, 1979) and will only be summarised here. In brief no detrimental effects of prolonged driving on performance were found although some apparently time-related changes did occur with shortest mean time headways occurring in the second and fifth hours of driving on both shifts. Because these hours were especially characterised by rural open road driving with little chance of any interruption to progress by traffic lights, junctions and so on it was argued that time headway selected by the driver might be in part a function of the perceived probability of sharp velocity decreases in the lead vehicle. Along these lines it was suggested that the time headway changes observed for hours 2 and 5 reflected a shift to a lower probability that a followed vehicle would slow down or stop. One implication of this hypothesis is of course that variations in time headway may not be construed exclusively as expressions of the level of risk exhibited by a driver.

In the replication of the late shift of this experiment it was found that time headway was reliably lower on the late shift than on the original early shift, particularly after hour 3 ($F_{11,88} = 2.67$, $p < .05$) and that time headway also decreased over time ($r = -0.51$, $p < .05$, one tail) to a level which for only hourly sample was on average almost 0.5 sec. less than the recommended safety headway of 2 seconds (see Table 1 below). However for a number of reasons it was again concluded that the results reflected a shift in the driver's estimate of the probability of velocity decreases in the lead vehicle. It was after hour 3 that the experimental lead vehicle had been introduced to provide a larger sample of following and it was estimated that this lead vehicle contributed about 80% of all following which occurred in the replication. It is suggested that drivers would have recognised the performance of the experimental lead vehicle as being more predictable than any vehicle they might chance to catch up with and that it would have a smaller probability of exhibiting sudden velocity decreases. Drivers could safely follow it more closely.

Table 1

Time Headway Means by Shift and Hour (Experiment 1)

Hour	1	2	3	4	5	6	7	8	9	10	11
Early shift	3.17	2.48	2.76	3.34	2.71	3.09	2.83	3.41	3.24	3.10	2.90
Late shift	2.58	1.84	2.16	2.18	1.48	2.12	1.82	1.98	1.81	1.54	1.96

Consistent with this interpretation of the results is the observation that hourly time headways for the late shift replication were lower than for the corresponding hours for the original late shift, particularly after hour 3 (t = 11.49, df = 17, p < .01). Further support is also provided by the finding that time headway was more closely associated with amount of experimental lead vehicle following than with hours driven: the partial correlation coefficient for time headway and hours of driving with percent time following the experimental vehicle held constant was r = -0.13 whereas for time headway and percent time following the experimental vehicle it was r = -0.26. In sum, shorter hourly time headways in the late shift replication were associated with longer periods of experimental vehicle following. Again, as in the first part of this experiment, the general conclusion is that no clear effects of prolonged driving on performance safety were found.

Given the above explanation for observed changes in time headway it was not surprising to find that in Experiment 2 (continuous two-vehicle convoy) time headways were on average reliably lower (mean = 1.76 sec., sd = 0.57) than under more normal following conditions (mean = 2.49, sd = 1.00) (t = 13.81, df = 1028, p < .001, two tailed) although this result may also be a direct consequence of the instructions to S to follow the lead vehicle fairly closely.

In Experiment 2 robust main effects were found for Shift ($F_{1,8}$ = 21.16, p < .01) and for Hours ($F_{10,80}$ = 16.43, p < .01). Mean time headway was longer on the late shift (1.93 sec.) compared with the early shift (1.62 sec.) and was also longer for the first hour (2.62 sec.) than for all other hours (range = 1.51-1.79 sec.--see Table 2). It should be noted that the shift variable appeared in two second order interactions which indicated that, although a persistent effect, it was not statistically reliable in all possible comparisons.

It appears from the results for hours driving that the first hour may constitute a period of adjustment to the performance of the lead vehicle driver, providing a warm up period to the demands of the task. However it is noteworthy that again there appears to have been no impairment in performance over time. Indeed the observation of longer time headway on the late shift indicates that drivers were more cautious under this condition, perhaps compensating for fatigue effects or taking account of the relative unpredictability of velocity decreases in the lead vehicle.

Table 2

Time Headway Means by Hour (Experiment 2)

Hour	1	2	3	4	5	6	7	8	9	10	11
	2.62	1.64	1.65	1.74	1.66	1.79	1.51	1.66	1.65	1.69	1.73

DISCUSSION

The main conclusion from these experiments must be that in terms of the performance measure employed, no unambiguous evidence of a relationship between driving riskiness and hours of driving has been found. And this conclusion, let it be reaffirmed, applies to professional drivers driving a 7-ton truck for 11 hours per day for 4 consecutive days either in a quasi-normal driving environment or in the more demanding task of following continuously another vehicle.

A key phrase in the conclusion stated above is of course "in terms of the performance measure employed" because at the outset of the studies, the measure of time headway was considered to be fairly readily interpretable in terms of driver riskiness: the shorter the headway, the riskier the situation. This assumption has already been challenged in the Results section where it has been argued that the time headway adopted by a driver may indicate also his response to the perceived probability of sudden deceleration in the leading vehicle. Where this is low, shorter headways are adopted and vice-versa. It is worth noting here that support for this expectancy hypothesis has also been obtained in an experimental car driving situation radically different from the conditions under which HGV drivers were required to drive in the present studies (see Colbourn et al., 1978). One further point might be added in this context. It seems likely that where the probability of lead car deceleration cannot be judged, for whatever reason, in such a condition of unpredictability drivers may adopt longer time headways. This interpretation was offered earlier to account for the longer time headways associated with the late shift in Experiment 2.

From the point of view of safety in vehicle following it should be noted that if drivers do adopt headways on the basis of expected lead vehicle velocity decreases, such a strategy is particularly vulnerable to the actual occurrence of the low probability event (lead vehicle slows rapidly) as well as to all the factors which might lead to the setting up of incorrect expectations, factors such as inadequate information or inadequate processing of the information that is available through lack of experience or impaired judgment.

Despite these considerations there appears to be no time dependent performance changes in the results which would lead one to conclude that, for example, performance in the 10th and 11th hours was more risky than that in the 7th and 8th hours. That this seems to be the case may be due, as suggested earlier, to an inordinately high level of motivation in the experimental drivers which was sufficient to overcome any decrement which would otherwise occur under more normal driving conditions. If this is a valid hypothesis then it shifts the problem of overcoming any detrimental effects of prolonged driving into the area of performance motivation rather than fatigue, stress or whatever.

On the other hand it could be that the time headway measure used was simply not sensitive enough to performance changes important for safety. Determining a driver's mean time headway for each hour of operation does not facilitate detection of brief, transient changes which may be of crucial importance and in addition it masks differences between different kinds of following manoeuvre. A recent preliminary study (Fuller, 1980) has found that various types of following manoeuvre such as closing on a leading vehicle, steady-state following, following immediately prior to overtaking and braking have reliably different time headway values. Such manoeuvres may be differentially sensitive to the effects of prolonged driving.

Finally, an alternative possibility may be put forward to explain not only present results but the general failure of experimental studies to demonstrate a clear relationship between prolonged driving and accident risk. Both the interpretation of accident data and the design of studies of fatigue and driving have in the past tended to make the tacit assumption that there is some sort of linear or simple curvilinear relationship between time and fatigue effects. However it could be argued that fatigue effects may be also in part a function of the anticipated duration and difficulty of the task to be undertaken and the relationship between such task expectations and what actually occurs.

It has long been known that in simple mental tasks rate of work is a function of the anticipated duration of the task (e.g., Forrest, 1958) and that energy expenditure may be regulated according to expected task demands (e.g., Jarrard, 1960). In a brief review of some of this evidence, Welford (1968) concluded that the experimental results were complementary to the well known fact that athletes pace their performance from the beginning of a race according to the distance to be covered (or duration of running) to avoid premature onset of exhaustion due to overexertion in the early stages. One might label this whole phenomenon "effort rationing" to capture the notions that first there is some limit to the effort available to carry out a particular task and second that this effort needs to be managed so that it is sufficient for the duration of the task.

In the normal work situation, of course, the worker knows for how long he must work and usually how hard he must work and is therefore well able to manage his effort appropriately, presumably avoiding severe fatigue effects. Similarly, in the experiments reported here, drivers were fully informed of the duration and nature of the work demands placed on them. But what happens if, because of irregular demands, a driver simply cannot manage his effort in this way or, having worked for the expected duration, further demands are made on him? It is worth asking how many road accidents have occurred not only after prolonged driving but also at a time later than when the driver had expected to have stopped or completed the journey.

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APPENDIX B

DETERMINANTS OF TIME HEADWAY ADOPTED BY TRUCK DRIVERS

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As a measure of driving performance, time headway provides a way of representing the total interaction between a driver, his vehicle and the road environment as well as an exact description of episodes of dangerously close following. This paper presents the results of a field experiment on the effects on time headway of prolonged driving in a continuous convoy situation.

In all, 12 professional truck drivers in two age groups were used. Each drove an instrumented 7 ton rigid van-type heavy goods vehicle for 11 hours on each of 4 consecutive days. Time headway was measured using a closed-circuit television system designed to provide a continuous record of instantaneous time headway. Conditions under which the drivers' following performances were measured were different types of following manoeuvre, prolonged driving and early and late shifts. Comparison with the results of an earlier study of incidental episodes of vehicle following provided an evaluation of the effects of infrequent versus continuous following.

The results showed that time headways in convoy driving are much lower than in naturally occurring following situations, particularly for steady-state following during daytime hours. It also appears that drivers need a period of time to adjust to the demands of convoy driving and that driving at night requires longer time headways. No evidence of an increase in performance riskiness was found either during the 11 hour driving day or cumulatively over the 4 days of the experiment.

1. INTRODUCTION

Driving in convoy is traditionally associated with the manoeuvres of military vehicles. With the increased frequency of escorted movements of cash, prisoners and V.I.P.s, and the inevitable episodes of close following by moving vehicles on high density roads, including motorways, convoys appear to be a regular feature of the contemporary road environment.

It is perhaps surprising, however, that the specific demands of driving in a convoy configuration, particularly over prolonged periods, do not appear to have been reported in the experimental literature. Earlier work by the author (Fuller, 1978, 1980a) on the effects of prolonged heavy goods vehicle (HGV) driving in following situations occurring spontaneously in traffic showed no observable deterioration in performance. However, naturally occurring following episodes constitute only about 2.5% of total driving time and both observation and drivers' reports confirmed the supposition that drivers generally seek to avoid having to take account of a leading vehicle either by overtaking it or dropping farther back. Thus convoy driving in which following accounts for virtually 100% of driving time must represent a major change in the task demands of driving and one which drivers would presumably avoid if possible. A principal aim of this study therefore was to attempt to determine whether or not HGV driving performance would become impaired under conditions of prolonged and continuous driving in a two-vehicle convoy.

One aspect of driving performance was selected for specific study in this experiment, namely the driver's headway, the interval maintained between the leading and following vehicle. There are a number of reasons for this. One is that, in a convoy of continuous following vehicles, it makes sense to express the performance of one vehicle in relation to the one it is following. But of more importance here, adopting too short a headway appears to be a major contributory factor in rear-end collisions. Heavy goods vehicles make a disproportionate contribution to most categories of road casualties (Neilson et al., 1979) and in particular the risk of being involved in a fatal accident is about twice that for a car (Riley and Bates, 1980). However, of significance for this analysis, prior to impact in fatal and serious accidents, HGVs are more likely than cars to be involved with another vehicle moving in the same direction (Neilson et al., 1979) and in Ireland rear-end collisions account for about 13% of all fatal and injury accidents (An Foras Forbartha, 1980). Thus using headway as a measure of driver performance provides a rather direct index of driver risk (Lehman and Fox, 1967). Other things being equal, the shorter the headway the greater the risk of collision.

Analyses of road accident statistics tend to support the view that there is a relationship between prolonged driving and accident risk (see, for example, Harris and Mackie, 1972), a view further endorsed by the marked decline in accidents involving HGVs in the U.K. after the introduction of a daily 10 hour limit on driving in 1970. However, although there is some experimental support for that hypothesis (Brown et al., 1970; Mackie and Miller, 1978), it remains a controversial issue (Fuller, 1978) and further evidence is clearly needed. If task-induced fatigue is important in driving it may well be revealed more unambiguously in the relatively high demand situation of continuous following. A further reason for the inclusion of prolonged driving as a major variable in this study is that it should enable an evaluation of the potential consequences for road safety of the E.E.C. legislation restricting the hours of driving of commercial vehicle drivers.

In sum, then, the aim of this study was to examine the effects of prolonged HGV driving on continuous close-following performance in a two-vehicle convoy.

2. METHOD

2.1. Performance Measure

The measure of performance used was drivers' time headway and its variability, calculated for each hour of driving. In a following situation, the distance from the following vehicle to the one in front is its distance headway and the time for it to get to where the leading vehicle is at any moment is its time headway. The significant advantage of time headway as a measure is that it takes account not just of the distance between vehicles but also their speeds. It was continuously monitored using a closed-circuit television system described in Fuller et al. (1978) and incorporating modifications reported in Fuller et al. (1980). The system was mounted on an HGV driven by S as the second vehicle in a two-vehicle convoy.

The system uses two forward facing TV cameras with an application of the coincidence principle for measuring distance. Images from the two cameras are superimposed in one monitor display. In this display any displacement between the separate images of an object viewed by the two cameras is inversely proportional to its distance away from them. Thus the distance of an object in front, such as a leading vehicle, can be determined simply by measuring the displacement between its two images on the monitor screen. Simultaneously, speed can be read from a speedometer coupled to the vehicle speedometer drive and with these two measurements time headway can be calculated for any one instant. Since following was continuous in this study, sampling rate for time headway was less than in earlier experiments using the system (see, for example, Fuller, 1978) being reduced from a 5s to an 18s interval.

2.2. Categories of Following Manoeuvre

Earlier studies of following performance have generally assumed that episodes of following are more or less equivalent. However, in naturally occurring following situations this has been shown not to be the case (Fuller, 1980b). In this study therefore, four specific classes of following manoeuvre were distinguished to provide an examination of the possibility of interactions between the independent variables and the different types of manoeuvre. The classes of following manoeuvre distinguished at the point of time headway sampling were as follows:

(a) steady-state following, where both vehicles had been in an unchanging 'coupled' state for a continuous period of 5s or more;

(b) closing, where the following vehicle had caught up on the leading vehicle for a continuous period of 5s or more, but brakes were not applied;

(c) closing-braking, where the following vehicle was braking at the same time as closing on the leading vehicle; and

(d) braking, where the following vehicle brakes were applied but the following vehicle was not closing on the leading vehicle.

In the analysis of results, two further classes of following data were obtained by combining some of the above categories as follows:

(e) steady state + closing ((a) + (b))--all following situations in which following vehicle brakes were not applied;

(f) aggregate ((a) + (b) + (c) + (d))--all following manoeuvres.

The relatively infrequent and brief situations in which the leading vehicle accelerated away from the following vehicle were ignored.

2.3. Experimental Design

In addition to the factor of hours, three other variables were manipulated, days of driving, age of driver and time of shift onset for the driver. Subjects were 12 volunteer professional army drivers each paid 80 pounds for participating in the project. Two age groups ('young' and 'old') were selected with mean ages of 22.7 years (SD = 1.0) and 33.5 years (SD = 4.7) respectively. Each S was required to drive an instrumented 7 ton Bedford rigid van-type truck for 11 hours on each of 4 consecutive days over a preselected route of approximately 300 miles which was repeated on each day. The route consisted of two different loops out of and returning to Dublin, the same loop being driven first on each day. Driving was continuous except for a 30 min meal break after 5½ hours and one 10 min break during each session. Subjects in each group were allocated at random for the duration of the experiment to one of two driving shifts which started at either 09.00 hours or 15.00 hours. This procedure was precisely the same as that adopted in the earlier studies of natural following episodes by Fuller (1978, 1980a) with the one major difference that drivers were instructed to follow continuously a leading Volkswagen 15 cwt van at such a distance as to prevent other vehicles from interposing, unless the interests of road safety dictated otherwise.

The leading vehicle was driven by three different drivers randomly allocated to 2.75 hour blocks of driving with the one constraint that no individual driver should drive for more than two consecutive periods on any 1 day.

The statistical design of the experiment then was a 2 x 2 x 4 x 11 factorial Anova with main factors of age (two levels), shift (two levels), day (four levels) and hour (11 levels), with repeated measures on the last two factors and n (cell) = 3. This Anova design was applied separately to the time headway and time headway variability data for each of the six categories of following manoeuvre described earlier, making 12 analyses in all.

2.4. Experimental Procedure

Each S attended a hospital endocrine unit on the day preceding the start of his driving sessions in order to be instructed in detail in the complete procedure for the experiment. He was asked to complete a short form of the Eysenck personality inventory (E.P.I.) and given a brief 'check-out' on the experimental vehicle. So that he would not be aware that his vehicle-following performance would be under systematic observation, S was informed that the purpose of the study was to determine the relationship between long hours of driving and hormone level changes and at his allocated shift onset time (09.00 hours or 15.00 hours) a 20 ml blood sample was taken. S was then given two bottles to collect his urine for the following two 5.5 hour periods. He was finally requested to return to the unit at the time corresponding to the termination of his driving shift for a further blood sample. Thus the first day was used both to familiarize S with the experimental procedure and to obtain reference base-line values for an endocrine analysis. It should be noted that results for that analysis and the questionnaire data do not form part of this report.

On the remaining four days of the experiment the procedure for S was largely the same as for the initial day with the major additional requirement that S carry out the convoy driving task as described earlier and routinely complete a checklist concerning his driving self-evaluation, motivation and feelings of fatigue. At the end of the last day S was required to complete an additional questionnaire which related to his reactions to the experiment as a whole and was finally paid for his participation.

3. RESULTS AND DISCUSSION

3.1. All Following Manoeuvres (Aggregate)

The analysis of variance for the pooled time headway data produced significant main effects for shift, day and hour (see table 1). Mean time headway for the late shift was longer (1.93s) than for the early shift (1.62s), was longer for day 1 (1.90s) than for day 2 (1.68s) and longer for hour 1 (2.62s) than for all other hours (range = 1.51-1.79s). As can be seen from table 1, however, none of these effects was independent. There was a significant first-order interaction between day and hour and significant second-order interactions for shift x age x day and shift x age x hour.

Table 1

Anova Summary Table for Aggregate Time Headway

Source of variation	SS	df	MS	F
Between subjects	16.631	11		
A (age)	1.339	1		
B (shift)	11.024	1	11.024	21.16**
AB	0.103	1		
Subj. w. gps	4.165	8		
Within subjects	130.422	516		
C (day)	3.496	3	1.165	3.05*
AC	0.419	3		
BC	1.393	3		
ABC	3.748	3	1.249	3.27*
C x Subj. w. gps	9.164	24	0.382	
D (hour)	37.789	10	3.779	16.43**
AD	1.935	10		
BD	1.863	10		
ABD	7.589	10	0.759	3.30**
D x Subj. w. gps	18.424	80	0.230	
CD	8.536	30	0.285	2.08**
ACD	3.520	30		
BCD	4.681	30		
ABCD	3.438	30		
CD x Subj. w. gps	24.427	178	0.137	

*$p < 0.05$. **$p < 0.01$.

For the day x hour interaction it was found that although on each day hour 1 obtained the longest time headway mean, there were exceptions where the difference was not statistically significant on day 2 and day 3. It is also worth noting here that the mean time headway for hour 1 of day 1 was significantly longer than for hour 1 on the subsequent 3 days of the experiment.

The two second-order interactions in this analysis indicated that age and shift interacted with both the day effect and the hour effect. In the first case, although the day effect was observable for both age groups of subjects and on both shifts, it was only statistically reliable for young drivers on the late shift (day 1 mean = 2.28s, day 2 mean = 1.77s). An alternative way of explaining this age x shift x day interaction is to look at the effect of age and day on the main shift effect. This analysis revealed that, although a generally pervasive effect, the difference between shifts was reliable only for young drivers on day 1 and old drivers on days 3 and 4.

With regard to the age x shift x hour interaction, further analysis revealed that although for all age x shift combinations hour 1 mean time headway was greatest, this was not significantly so in all comparisons. In particular the comparison between hour 1 and remaining hours was not significant for the old drivers on the late shift for hours 2, 4 and 6-11. These results are presented in table 2. Finally another way of examining this interaction is in terms of the age x hour interaction and the main shift effect. In all but two of the 22 shift comparisons possible, the late shift mean was greater than that for the early shift and the differences for the two 'reversals' were also negligible (see table 2). However it was found that this shift effect was statistically reliable only for the young drivers on hour 1 and the old drivers on hour 11.

Table 2

Aggregate Time Headway Means for Age-Shift-Hour Interaction

		Hour										
		1	2	3	4	5	6	7	8	9	10	11
Young	Early	2.30	1.48	1.59	1.63	1.54	1.80	1.47	1.64	1.64	1.69	1.71
	Late	3.50	2.04	1.93	1.90	2.03	1.91	1.59	1.77	1.64	1.68	1.67
Old	Early	2.47	1.35	1.44	1.55	1.41	1.59	1.32	1.52	1.66	1.48	1.38
	Late	2.39	1.76	1.70	1.94	1.71	1.89	1.73	1.75	1.94	1.97	2.21

For aggregate time headway variability (the standard deviation of time headway determined for each hour of driving), two significant main effects were found for shift ($F(1,8) = 7.05$, $p < 0.05$) and for hour ($F(10,80) = 8.48$, $p < 0.01$). For the shift effect, mean variability on the late shift (0.85s) was greater than on the early shift (0.65s) and for the hour effect, mean variability on hour 1 (1.56s) was greater than on all other hours (range = 0.50-0.91s).

In general drivers adopt longer and therefore safer headways at the beginning of the shift, in the earlier stages of the experiment and on the later shift. The further finding that time headway variability is greater in the first hour and on the late shift lends support to the notion that what is being revealed here may be a pattern of drivers' adjustment to the demands of the convoy driving task, driving at a lower risk level when conditions are perhaps more demanding. Presumably close-following requires a period of practice during which time the driver of the following vehicle adjusts to the performance of the leading vehicle and it is noteworthy that the longest mean time headway in the experiment occurred for the first hour of the first day. Furthermore it may be the case that late shift driving is more demanding because of such factors as lowered arousal level and/or decreased visibility. Approximately 80% of time driving on the late shift employed here was during hours of darkness.

3.2. Convoy Versus Normal Following

The aggregate time headway results were compared with the results for naturally occurring following episodes obtained in an earlier study (Fuller, 1978) which used the same experimental design and procedure as the current experiment except for the continuous convoy mode of driving in the latter. A comparison with the results for the original early shift only was possible because of the paucity of naturally occurring following episodes on the original late shift. The time headway mean for the original early shift was 3.01s (SD = 1.05), for the convoy early shift 1.62s (SD = 0.46) and for the convoy late shift 1.93s (SD = 0.64). A t-test comparison between the natural and convoy headway means revealed that time headway on both convoy shifts was significantly shorter than under conditions in which following occurred spontaneously (convoy early shift versus natural early shift, t = 19.86, df = 534, $p < 0.01$ two-tailed; convoy late shift versus natural early shift, t = 13.50, df = 492, $p < 0.01$, two-tailed). This result reveals an interesting reduction from the relatively long, self-selected time headway under conditions of normal following to the relatively short headways adopted under conditions of convoy driving, where the driver of the following vehicle is attempting to keep up with the leading vehicle and prevent other vehicles from coming between him and it. It is to be noted that in the latter condition on the early shift, mean time headway was on average almost 0.4s <u>less</u> than the recommended 2s minimum time headway.

3.3. Classes of Following Manoeuvre

3.3.1. General Results. For each class of following manoeuvre the mean number of observations per hour, relative frequency of occurrence and mean time headway are presented in table 3. The frequency values provide an approximate indication of the amount of driving time spent in motion in each manoeuvre and it may be seen that most time was spent in steady-state following (82%), that steady-state following and closing together accounted for about 95% of total driving time in motion and that periods of braking accounted for only about 5%. The time headway results indicate that steady-state following and closing were characterised by relatively short headways whereas headway samples involving braking were relatively long. A series of *t*-tests revealed that there was no significant difference between the means for steady-state following and closing or between closing-braking and braking, but all other comparisons were significant (steady state versus closing-braking, $t = 11.83$, df = 799; steady state versus braking, $t = 9.97$, df = 727; closing versus closing-braking, $t = 11.35$, df = 779; closing versus braking, $t = 9.37$, df = 697--all $p < 0.001$, two-tailed). It appears that when braking, whether or not physical distance between vehicles is being reduced, there is on average an increase in time headway, representing a positive deceleration of the following vehicle relative to the leading vehicle. The observed values are remarkably close to corresponding values reported in an earlier study (Fuller, 1980b), in which a second vehicle was used at intervals as a leading vehicle to create occasional following situations for the driver of the experimental HGV. This result implies that under the conditions of these studies the time headways associated with particular manoeuvres are quite reliable.

Table 3

Classes of Following Manoeuvre: Frequencies and Time Headway Values

	Mean per hour	Percent total time	Mean time headway(s)
Steady state	89.95	82.2	1.70
Closing	13.86	12.7	1.63
Closing-braking	3.69	3.4	2.66
Braking	1.90	1.7	2.42

3.3.2. Effects of Age, Shift, Day and Hour. A summary of the main time headway and headway variability results for each class of manoeuvre is presented in table 4. A more detailed presentation of the results is provided in Fuller (1981).

For steady-state following, longer time headways were associated with the first hour of each day and with late shift driving. Performance was also more variable during the first hour but at the other end of the driving day, there was no suggestion of a performance decrement, even after the fourth day of prolonged driving.

In the closing manoeuvre, as for steady-state following, the first hour of the day was again associated with longer and more variable time headways. Longer time headways were also found for the first day of the experiment, particularly for younger drivers on the late shift. This result implies greater caution by the younger drivers, whose mean time headway was longer overall and could reflect either an unusual age difference in acceptable risk or rather a difference in rate of adaptation to the demands of the experiment. The younger driver may require more time to adjust to the task of convoy driving. Lastly, again no evidence was found for a deterioration in performance as a consequence of prolonged driving.

Table 4

Classes of Following Manoeuvre: Summary of Significant Main Effects and Interactions in Anova Results

Manoeuvre	Significant comparisons (units are seconds)
(a) Steady state	
Time headway	
Shift $F(1,8)$ 27.16**	Late: 1.86 > early: 1.57
Hour F (10,80) 11.15**	Hour 1: 2.23 > all other: 1.50-1.74
Day x hour $F(30,167)$ 1.70*	Hour effect not reliable for all hours on day 3
Time headway variability	
Hour $F(10,80)$ 3.20**	Hour 1: 0.99 > hours 3, 4, 7, 9, 10, 11
(b) Closing	
Time headway	
Age $F(1,8)$ 6.00*	Young: 1.73 > old: 1.53
Shift $F(1,8)$ 11.17**	Late: 1.77 > early: 1.50
Day $F(3,24)$ 5.12**	Day 1: 1.78 > day 2: 1.55 and day 4: 1.57
Hour $F(10,80)$ 10.86**	Hour 1: 2.61 > all others: 1.27-1.80
Age x shift x day $F(3,24)$ 4.60*	Day effect reliable mainly for young drivers on late shift
Age x hour $F(10,80)$ 3.20**	Hour effect reliable for young drivers only
Time headway variability	
Hour $F(10,80)$ 3.74**	Hour 1: 1.12 > all others except hour 6: 0.34-0.56
(c) Closing-braking	
Time headway	
Shift $F(1,8)$ 6.39**	Late: 3.21 > early: 2.28
Hour $F(10,80)$ 3.94**	Hour 1: 3.64 > hours 2-8: 2.19-2.46 Hour 11: 3.42 > hour 5: 2.23 and hour 8: 2.19
Age x shift x day x hour $F(30,81)$ 2.02*	Long headway for hour 1 characteristic of both age groups and shifts but for hour 11 is mainly characteristic of old drivers on late shift
Time headway variability	
Hour $F(10,80)$ 3.19**	Hour 1: 1.53 > hours 5, 6, 8, 9
Shift x day $F(3,24)$ 5.14**	Late shift day 4: 1.70 > early shift day 4: 0.67
Age x shift x hour $F(10,80)$ 2.76**	Hour effect reliable only for young drivers on late shift

Table 4 (Continued)

Manoeuvre	Significant comparisons (units are seconds)
(d) Braking	
Time headway	
Day $F(3,24)$ 3.67*	Day 1: 2.55 > day 2: 2.11
Hour $F(10,80)$ 4.22**	Hour 1: 3.58 > all other: 1.93-2.47
Day x age $F(3,24)$ 4.54**	Day effect reliable only for old drivers
Day x shift $F(3,24)$ 4.28**	Day effect reliable only for early shift drivers
Age x hour $F(10,80)$ 3.88**	Hour effect reliable only for old drivers
Time headway variability	
Hour $F(10,80)$ 2.18*	Hour 6: 0.65 > hour 9: 0.19 and hour 10: 0.16
(e) Steady state + closing	
Time headway	
Shift $F(1,8)$ 24.48**	Late: 1.85 > early: 1.56
Day $F(3,24)$ 3.61*	Day 1: 1.82 > day 2: 1.64 and day 4: 1.63
Hour $F(10,80)$ 13.00**	Hour 1: 2.32 > all other: 1.49-1.72
Age x shift x day $F(3,24)$ 3.65*	Shift effect reliable day 1, young drivers and days 3, 4 for old drivers
Age x shift x hour $F(10,80)$ 3.31**	Hour effect not reliable young early and old late drivers
Day x hour $F(30,178)$ 1.67*	Hour effect not reliable all hours day 3
Time headway variability	
Hour $F(10,80)$ 5.38**	Hour 1: 1.17 > all other: 0.45-0.80

$^{*}p < 0.05$. $^{**}p < 0.01$.

The results for closing-braking indicate that when closing on the vehicle in front, braking tends to occur earlier on the late shift, during the first hour of driving, and during the last hour of driving, particularly for old drivers on the late shift. The evidence also indicates that closing-braking is more variable during the first hour of the late shift for young drivers and becomes more variable on the last day of the late shift for all drivers.

The closing-braking class of following manoeuvre occurs mainly when the following driver has to respond to a velocity decrease in the vehicle in front. In responding to such decreases in speed, ability in controlling rate of approach to the leading vehicle may be vulnerable to a number of factors such as inappropriate arousal level, inadequate practice and impaired visibility. If these factors do have the potential to impair judgement then it makes sense for drivers to compensate by braking earlier when closing under such conditions. Thus long closing-braking time headways may imply caution and perhaps compensation.

In these results longer time headways are associated with early periods of driving, when practice may be inadequate and arousal level inappropriate; with the end of the driving day, when visibility and arousal may be impaired and with the later shift, when again visibility and arousal may be impaired. Furthermore increased variability in performance is also related to some extent to these variables, occurring in the first hour of the late shift for younger drivers and on the last day of the late shift for all drivers.

Finally for closing-braking there is some slight evidence that the older drivers are perhaps more vulnerable to the cumulative effects of prolonged convoy driving. On the late shift the young group alone showed a decrease in performance variability over hours whereas the older drivers tended to adopt significantly longer headways in the 11th hour (assuming that this is a compensatory response). However, despite this possibility, there is no real evidence that after long hours of driving in convoy, drivers tend to be closer to the vehicle in front before braking. Apart from the observed deterioration in performance variability, all of the statistically reliable effects may be interpreted as representing shifts toward decreased riskiness in vehicle following performance.

Long time headways in the braking manoeuvre may be unambiguously interpreted as an index of caution in driving in convoy. Thus the time headway results here suggest greater caution on the part of older drivers during the first hour and on the first day, at least in the early shift. These results appear to be quite consistent with the practice and arousal hypotheses outlined earlier for the aggregate results and discussed above in the context of the closing-braking results. The observed age difference, however, contrasts with that found for the closing manoeuvre and raises an interesting but unanswered question. Are the longer time headways associated with the older drivers a reflection of the adoption by them of a less risky following strategy, or do they reflect a necessary compensatory response to the demands of the task?

Not surprisingly, the time headway results for the combined steady-state and closing manoeuvres reflect those already found separately for those two categories and for the aggregate data. Thus with slight variations the effects for shift and hour in the steady-state and closing results are repeated and in addition the day effect in the results for closing time headway has also appeared in the combined results. Again the interpretation favours identification of something like a practice effect in the longer headways for hour 1 and day 1. The shift difference with longer headways associated with the late shift also appears quite robust and again presumably reflects the relative difficulty of close following on the late shift.

The importance of combining these two time headway categories, however, lies in the opportunity to provide a more comprehensive estimate of time headway variability in normal following. The results here confirm the earlier finding, namely that performance in hour 1 is more variable than in all other hours. The persistence of this effect lends further support to the practice interpretation posited above. Drivers apparently need a period of time to adjust to the demands of convoy driving.

4. GENERAL DISCUSSION AND CONCLUSIONS

Convoy driving as defined in this study clearly imposes abnormal demands on the driver in that convoy headways have been found to be generally much shorter than those selected under free driving conditions and much shorter than the 2s minimum recommended by road safety authorities, particularly during daytime driving. Despite this there appears to be no real evidence of sustained impairment in performance as a function of prolonged driving either on each day or over the 4 days of the experiment.

However, generalizations from a field study such as this cannot of course be made without qualification. Results might not be the same with different types of HGV, freight, driving duties, road environments and under normal work patterns.

Even if progressively decreasing headways had been observed over time, this need not necessarily have constituted evidence of performance impairment. Although shorter headways per se are more risky, the accident potential of short time headways must in part and within limits be determined by driver capability. This may improve in such a way as to compensate and perhaps more than compensate for the additional demands of the shorter headway. A general implication here for performance measurement in driver behaviour is that the riskiness of short time headways cannot be unambiguously determined in isolation from a concurrent measure of driver capability.

As suggested earlier two characteristics of the drivers' performance could account for the major part of the results obtained: first, that there appears to be a need for a period of adjustment to the demands of the convoy driving task; and, second, that more caution in following performance is shown in the later shift.

That there is a need for a period of adjustment to the demands of the continuous convoy driving task is strongly suggested by the finding that, for all categories of following, mean time headway was longest for the first hour of each day. This is further supported by the observation that, for three of the four discrete following manoeuvres, variability in time headway was also greatest for the first hour. The conclusion then is that a period of about an hour is required for drivers to settle down to steady, close following in a convoy situation. One practical implication here is that in controlled convoy driving, and presumably in any continuous following situation, drivers should not be constrained to short time headways for the early part of a journey. Results also indicate that different aspects of following performance may show varying patterns of adjustment by different drivers.

The interpretation that drivers displayed more caution on the later shift is based on the finding that for three of the four types of following manoeuvre mean time headway was longer on that shift. Why drivers should do this is a matter for conjecture. One possible reason suggested earlier is that the reduced visibility associated with about 80% of late shift driving made close following more difficult. If this explanation is valid then the longer headways adopted by drivers would represent a safety-oriented adaptation to increased task difficulty.

An additional possibility is that on the later shift the subject's arousal level was much more likely to fall below the level required for optimal following performance, particularly since the last few hours of the shift coincided with periods during which the driver would normally have been asleep. Thus drivers may have 'dropped back' in order to decrease the performance demands on themselves, thereby compensating for any reduction in capability. In any event one implication of this result is that, in convoy work at night, drivers appear to prefer significantly longer headways than during daytime driving, and vehicle spacing should take account of this.

Lastly it should be noted that some age differences in adjustment to the various demands of prolonged convoy driving have been found in this study with the implication that it may be advisable to select drivers for specific schedules of convoy duty and although the focus of interest here has been on the controlled convoy, the findings may also obtain for incidental convoys of commercial vehicles in high density traffic.

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APPENDIX C

UNOBTRUSIVE TECHNIQUE FOR CONTINUOUS RECORDING OF AUTOMOBILE HEADWAY[1]

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Summary.--A system is described for the continuous recording of vehicle headway, suitable for use in most types of vehicle. It has the distinct advantages of being robust, reliable, does not involve any connection with a lead vehicle and the driver need not be aware that his vehicle-following performance is under investigation.

In an earlier report by Fuller et al. (1978) a system for measuring vehicle headway was described which made use of the calibrated displacement of the super-imposed images from two closed-circuit television cameras mounted on an experimental vehicle and viewing a length of road from immediately in front of the vehicle to a distance of about 200 ft. Although that system has been demonstrated to be accurate, reliable, and robust over more than 20,000 miles of continuous operation, it has the particular disadvantage of relying on the power supply from a petrol-driven AC generator. This design feature effectively limits the use of the system to vehicles in which the generator can be suitably housed (such as a large van or truck). Furthermore in order for the generator fuel tank to be refilled safely it is necessary to stop the experimental vehicle every 2.5 hr. or so.

An alternative system has now been developed and tested successfully over approximately 20,000 miles which dispenses completely with the petrol-driven AC generator by making use of the vehicle's own electrical power supply. This is modified to provide an increased output and is used in conjunction with a blocking diode, an additional accumulator (battery) and an inverter. To increase the electrical supply the standard vehicle alternator is replaced by a 60-amp 12-V DC unit, e.g., Lucas AC 5, and the output from this is passed to a blocking diode which ensures electrical isolation of the vehicle's own accumulator and an additional one (95 AH capacity). This latter is used to supply the headway monitoring and recording system via an inverter with output maximum of 400 W at 240 V 50 H_z (square wave). The inverter employed can of course vary depending on the electrical supply required for the system used. Thus if a video tape-recorder is not used and direct measurements are taken from the video display, an inverter of only 150 W output would be adequate. It should also be noted that all of the equipment described for the original headway-recording system operates successfully

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with a square wave output from the inverter with the one difference that the monitor display is slightly foreshortened in the horizontal axis. Although this does not affect the use of the system in any way, it can be eliminated with the use of a sine wave inverter.

The disadvantages of the original system are completely avoided in the new system. Thus not only is the requirement to stop every 2.5 hr. removed but using this system headway can be measured not just in truck and van driving but in car driving. This development is useful because continuous measurement of headways adopted by experimental car drivers has proven to be a particularly difficult problem and several researchers have had to rely on a method in which the following car is attached to the lead car by a continuous wire held under tension by a "yo-yo" device (e.g., Olson, 1974; Colbourn et al., 1978). This unavoidably distorts the nature of the driving task for the subject and similarly may focus attention unduly on the separation of the vehicles. As in the original system, the modified system described here is unobtrusive, does not involve any connection with a lead vehicle, and the driver may be completely unaware of the aspect of his driving performance which is being monitored.

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APPENDIX D

PROLONGED DRIVING IN CONVOY: THE TRUCK DRIVER'S EXPERIENCE

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ABSTRACT

Self-ratings of performance, feelings of fatigue, and motivation were obtained from 12 Army truck drivers who were required to drive the second vehicle of a two-vehicle convoy for 11 hours on each of 4 consecutive days on either an early or late shift.

Drivers at the end of the late shift reported symptoms of performance deterioration, drowsiness, and exhaustion and were more inclined to want to stop driving. These symptoms were slightly more characteristic of the older drivers for whom serum cortisol levels were also relatively elevated.

The discrepancy between these findings and the marked absence of any increase in objective performance riskiness reported earlier was interpreted to be due to the drivers' compensatory adjustment in following distance when fatigued.

INTRODUCTION

In an earlier paper by the author the effects on driving performance of prolonged driving in convoy were reported (Fuller, 1981). It was concluded that on the basis of the performance data alone there was no real evidence of impairment as a function of prolonged driving, either over an 11-hour period or over 4 consecutive days of driving for 11 hours each day. Impairment was defined in that study in terms of the adoption of a shorter and therefore riskier time headway by the driver of the following vehicle. For most drivers no significant change in headway occurred after the first hour and indeed for older drivers required to drive until 02.30 hours each day there was evidence of a progressive <u>increase</u> in time headway over the last 3 hours of driving.

Nevertheless the absence of any apparent deterioration in performance does not necessarily imply the absence of other changes which might have implications for safety. Performance may be maintained at a given level but only at the expense of decreased efficiency, decreased energy reserves, impairment of functions unrelated to the task in hand, decreased capability to cope with increased load and perhaps increased vulnerability to long-term health hazards such as gastrointestinal disorders. As has been argued by Cameron (1973), performance measures can be erratic and unreliable indicators of fatigue. The onset of a breakdown in adaptation to the demands of a work situation may occur without there being any short-term change in performance at all.

Appley and Trumbull (1967) have similarly argued that the existence of a state of stress is shown not by specific changes in performance but by the mobilisation of biological coping mechanisms. The psychological equivalent of these might include symptoms such as feelings of exhaustion, tension, anxiety, or drowsiness, accompanied perhaps by a desire to avoid high demand situations or even to stop work altogether. In the absence of the normal constraints of modern working such feelings might be regarded as components of an adaptive expression of an impending inability to cope with the demands of the situation--as a sort of psychological early warning system for the approach of breakdown. As such they merit close scrutiny in conjunction with observations of physiological and performance change. This paper attempts such a scrutiny by presenting an analysis of drivers' own ratings of their performance, feelings of fatigue, and motivation to continue driving whilst engaged in the prolonged convoy task described earlier. Recorded changes in a number of endocrine variables will be related to that analysis.

METHOD

Two age groups of six volunteer army truck drivers with mean ages of 22.7 years (sd = 1.0) and 33.5 years (sd = 4.7) respectively were required to drive an instrumented 7-ton Bedford rigid van-type truck over two 5.5-hr loops on each of 4 consecutive days. Half of each group commenced at 09.00 hours and the other half at 15.00 hours. Driving was continuous except for one 30-min meal break midway and two 10-minute breaks halfway through each 5.5-hr loop. Total driving time was 11 hours per day, the driving span was approximately 11.5 hours, and the distance covered about 300 miles.

The driving task involved continuous following of a leading 15-cwt VW van at such a distance as to prevent other vehicles from intervening unless safety considerations dictated otherwise. Drivers' time headway performance was continuously monitored and blood and urine samples were collected at intervals to provide a record of changes in a range of endocrine variables. For details of these procedures see Fuller (1981). It should be noted that drivers initially reported on the day before driving so that baseline endocrine samples could be obtained. At the start of each day drivers completed a short questionnaire concerning their night's sleep and feelings immediately before driving. After each 5.5-hour block of driving they also completed a further questionnaire, administered by an assistant, concerning their driving performance, feelings of fatigue, and motivation to continue driving. Details concerning the design of these questionnaires have been reported in Fuller (1978). On completion of the experiment drivers were each paid 80 pounds for their participation.

RESULTS AND DISCUSSION

Predriving Conditions

Sleep. There was little change in quality of sleep over the 5 days of the experimental period (see Table 1) although there was some evidence of slight improvement from the night before the day on which base-line blood samples were taken to the first day of driving. No night's sleep was described as worse than "moderate" and drivers on the late shift did not appear to have had a poorer quality of sleep than subjects on the early shift (Table 2) or to sleep for less time than those subjects (Table 3). On the other hand the younger drivers on average took more sleep (7.9 hours) than the older drivers (6.9 hours) but this difference is not significant (t = 1.98, df = 10, p > .05).

Table 1

Quality of Sleep Before Each Day (No. of Nights)

"How well did you sleep?"	Very well	Well	Moderately	Badly	Very badly
Pre baseline	3	9	-	-	-
Pre day 1	8	4	-	-	-
Pre day 2	8	2	2	-	-
Pre day 3	8	2	2	-	-
Pre day 4	5	4	3	-	-

Table 2

Quality of Sleep of Drivers on Early and Late Shifts (No. of Nights)

	Very well	Well	Moderately
Early shift	17	9	4
Late shift	15	12	3

Not surprisingly the late shift drivers awoke about 2.5 hours later than the early shift drivers but what stands out here is the considerably larger variation in awakening time for the late shift drivers, an increase from 30 minutes to 2 hours and 15 minutes (Table 3). Despite the general absence of any effects of shift onset on the quality and duration of drivers' sleep, the late shift certainly seems to have been associated with a relatively marked irregularity in the sleep-wake cycle.

Table 3

Duration of Sleep and Time of Awakening

		Duration (hr)		Time of awakening	
		Mean	s.d.	Mean	s.d.
Early	Young	8.1	0.9	07.48	0 hr 24 min
	Old	6.7	1.2	07.12	0 hr 36 min
Late	Young	7.8	2.5	10.42	2 hr 30 min
	Old	7.1	1.4	09.30	2 hr 00 min

Feelings During Hour Prior to First Blood Sample. Examination of those occasions on which some feelings were expressed for the hour immediately preceding the first blood sample on each day (i.e., before driving on all days except the first) yielded no particular pattern or characteristic associated with either shift or age group (Table 4). Furthermore when particular feelings were expressed they were generally "slight" although one young driver before the third day of driving described himself as very drowsy and very exhausted.

Table 4

Frequency of Feelings Expressed for Hour Before First Blood Sample of Day

		Drowsiness	Boredom	Irritation	Exhaustion	Physical discomfort
Early	Young	3	-	-	3	-
	Old	2	-	1	2	1
Late	Young	2	2	-	2	-
	Old	2	1	2	-	1

Driving Performance

Recorded changes in ratings of driving performance were not large on any dimension and would normally merit little comment were it not for the fact that they tend to fall into a distinct pattern. This pattern is perhaps most immediately apparent from inspection of the graphs presented in Figure 1 in which the relationship between hours of driving and summed ratings of aspects of driving performance are shown. It may be seen that as assessed by the drivers themselves there is a general, albeit slight, deterioration in performance characteristic of the later stages of the late shift.

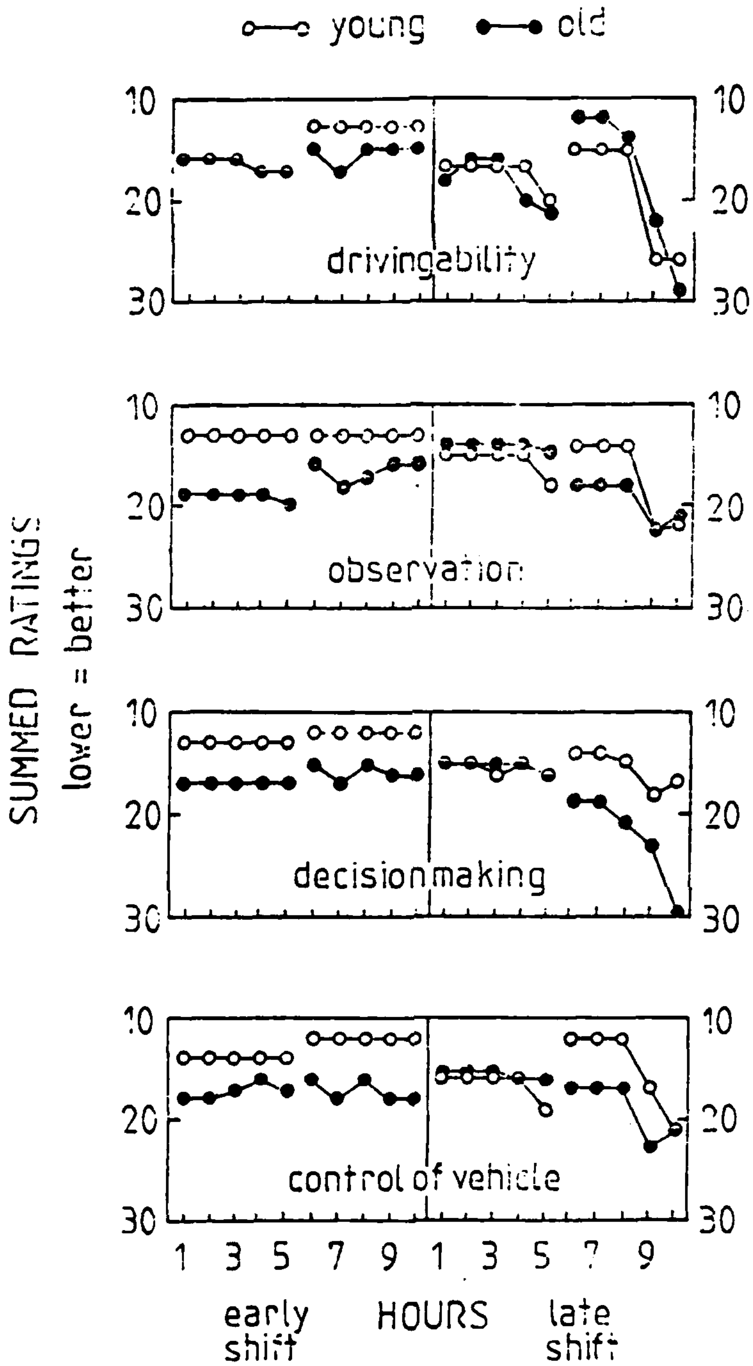

Figure 1. Hours of driving and summed ratings for aspects of driving performance.

Driving Ability. Although there was no effect of hours on overall ratings of driving ability there was for the late shift (Friedman two-way Anova, $X_{r}2 = 27.30$, $df = 9$, $p < .01$). Particular deteriorations in performance were rated for the last two hours of driving (mean = 2.15) compared with all other hours (mean both shifts = 1.32). Inspection of the data revealed that this pattern was independent of days.

Observation. Time related decreases in ratings for observation were slight but as for driving ability were characteristic of the last 2 hours of the late shift (mean last 2 hours of shift: 1.81, first 2 hours of shift: 1.22). Analysis of each day however indicated that this pattern occurred only on the first and last days of driving.

Decision Making. For this dimension of driving performance, some deterioration was again associated with the latter end of the late shift (Friedman $X_{r}2 = 18.38$, $df = 9$, $p < .05$) and in this case particularly for the older drivers (old driver mean, last 2 hours of shift: 2.21, first 2 hours: 1.25). Inspection of the data revealed the main effect to be repeated on each day.

Control of Vehicle. From inspection of Figure 1 it may be seen that there was a slight deterioration in rated control of vehicle for the last 2 hours of the late shift. However the effect for hours on this shift just failed to reach significance (Friedman $X_{r}2 = 14.73$, $df = 9$, $p < .1$). Nevertheless the pattern was found to be characteristic of all days except day three.

Riskiness. There was no general effect of hours on ratings of riskiness. Despite this, of the 10 recorded instances in which drivers rated themselves as "slightly risky" (see Table 5), 9 occurred on the late shift for older drivers. Furthermore, although there were only two instances in which drivers rated the category "quite risky" they were both associated with an older driver on the last 2 hours of the late shift.

Table 5

Ratings of Riskiness: Frequencies in Each Category

Not at all risky	Slightly risky	Moderately risky	Quite risky	Very risky
467	10	1	2	0

Courtesy to Other Road Users. There was no effect of hours on ratings of courtesy although it is perhaps worth noting that the drivers showing least courtesy, according to their own admission, were the young group on the late shift (young group mean: 1.7, all others: 1.2).

In summary then it appears that although changes in drivers' ratings of performance were slight, some deterioration was particularly associated with the later stages of the late shift. This phenomenon was statistically reliable for ratings of driving ability and decision making and a similar trend was found also for observation and control of vehicle. Although ratings of riskiness appeared to be independent of time driving the marked tendency for increases in riskiness to be associated with the late shift is consistent with the other results.

Feelings of Fatigue

As with ratings of driving performance, ratings of feelings on various dimensions of "fatigue" did not show dramatic changes over time. However in the light of the pattern of performance deterioration toward the end of the late shift observed earlier it is interesting to note indications of similar trends in the data for subjective feeling state. These may be seen graphically in Figure 2.

Drowsiness. A significant effect of hours on drowsiness was found (Friedman $X_{r}2 = 28.78$, $df = 9$, $p < .001$) with gradual increases in drowsiness occurring over time on each half session (Figure 2). Inspection of the results for each shift however revealed that increased drowsiness in the early shift was associated with the first half only and that the main deterioration occurred in the second half of the late shift, particularly in the last 2 hours (Figure 2). An examination of the results for each day separately showed this effect to be independent of days. It is perhaps worth noting that the change in average drowsiness during the late shift was from not at all drowsy during the first 2 hours ($\bar{X} = 4.90$) to moderately drowsy in the last 2 hours ($\bar{X} = 3.31$).

Exhaustion. Although the effect of hours on ratings of feelings of exhaustion failed to reach significance (Friedman $X_{r}2 = 14.13$, $df = 9$, $p < .1$) an apparent deterioration during the last hour of driving was found to be particularly associated with the late shift (Figure 2) and to be independent of days. Despite this the mean rating for the last hour of driving on the late shift ($\bar{X} = 3.92$) was equivalent only to a judgment of "slightly exhausted."

Awareness of What Doing--Daydreaming--Hallucinations. There was very little variation in drivers' ratings of "awareness-of-what-you-were-doing" and there was no effect of hours. The only observation of note was the evaluation of one driver on the late shift who for the last hour on two consecutive nights rated himself as "slightly aware" and then "not at all aware" respectively.

As was found for awareness ratings, there was also no relationship between hours of driving and probability of daydreaming (Table 6). There was however a marked age difference. Whereas older drivers were just as likely to daydream on the early ($p = 0.18$ per hour) as on the late shift ($p = 0.17$ per hour), younger drivers distinctly preferred the late shift (early shift $p = 0.03$, late shift $p = 0.27$) and especially the last 2 hours of that shift ($p = 0.50$).

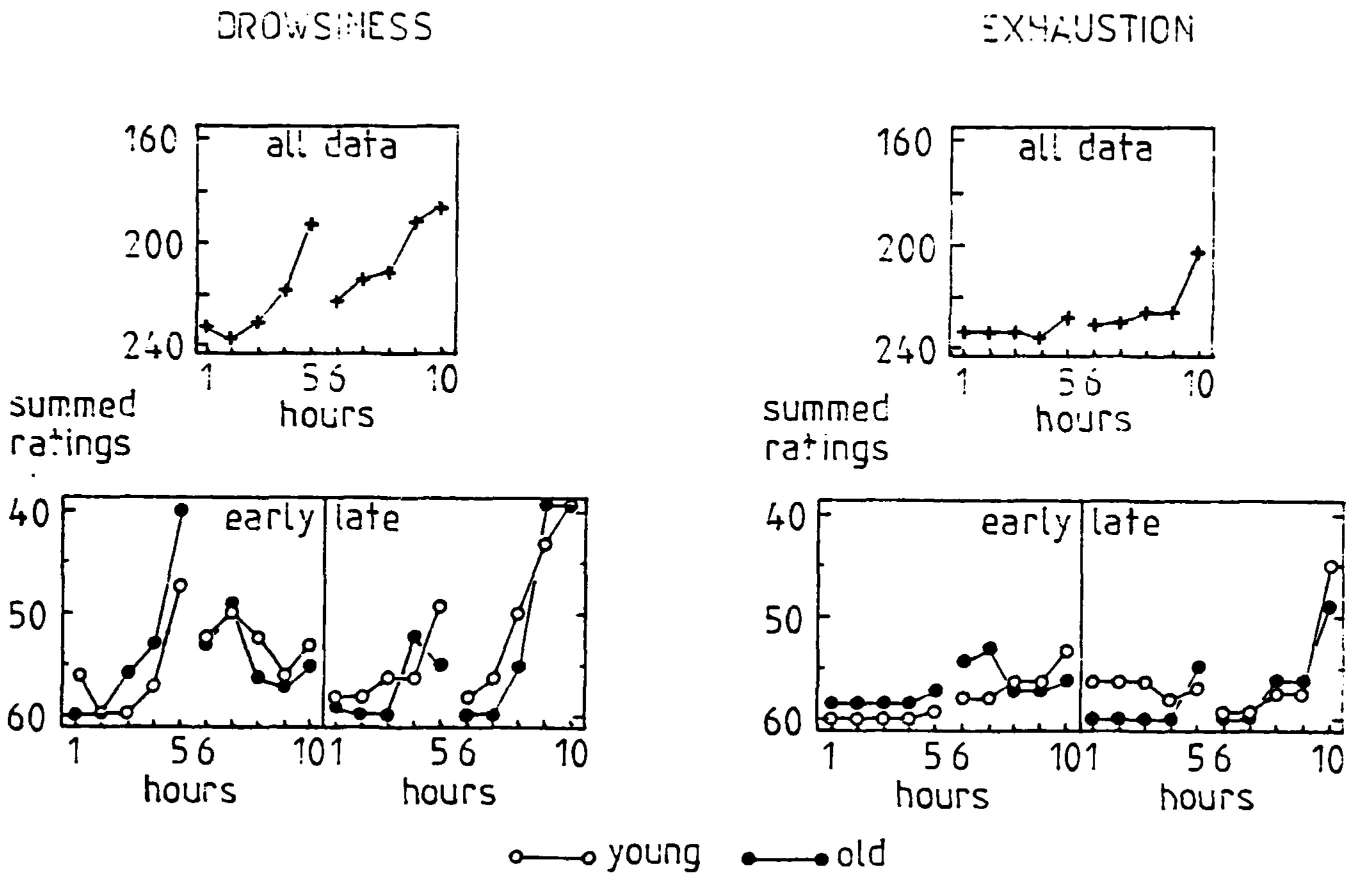

Figure 2. Hours of driving and summed ratings for drowsiness and exhaustion.

Table 6

Daydreaming: Number of Drivers Reporting It per Hour

		Hours									
		1	2	3	4	5	6	7	8	9	10
Early	Young	-	-	-	-	1	-	-	2	-	-
	Old	3	1	-	2	4	3	4	1	1	2
Late	Young	1	2	1	3	4	3	3	3	6	6
	Old	1	2	2	2	4	2	2	2	1	2

Lastly, nine instances of hallucinations or "seeing things which weren't there" were reported and it is significant and consistent with other results that all of these instances occurred on the late shift with six of them happening in the last 2 hours of the shift.

Physical Comfort. Although conceptually not directly related to the five other measures of feelings of fatigue, ratings of physical comfort were also routinely obtained. No effects of hours on ratings were found but it might be noted that the overall mean rating for comfort was 2.25 (worse than "quite comfortable") and that young drivers on the late shift had the highest mean of 3.19 (all others: 1.94).

In summary, increases in drowsiness and to a lesser extent exhaustion were associated with the last hour or two of driving on the late shift. This is of course not particularly surprising as at that time drivers would normally have been asleep. Nevertheless, the evidence, slight as it is, points to a possible decrease in driver capability at that time and the contemporaneous increased tendency for younger drivers to daydream and for hallucinations to occur reinforces the conclusion.

Motivation

Drivers' motivation during the prolonged convoy driving task was evaluated in two ways, first by asking them at the end of each half session (i.e., after each 5.5-hr period of driving) how prepared they were to drive on for a further period of time and second by asking them to rate their feelings on dimensions such as boredom and irritation.

Preparedness To Drive on for Longer. Considering the data for all half sessions it was found that on 44% of occasions drivers would like to have driven on for longer (mean: 2.1 hr), on 28% they would like to have stopped earlier (mean: 1.3 hr), and on 28% they found the time about right. However as can be seen from Table 7, comparing the end of the second half with the end of the first half (i.e., after 11.0 hr compared with 5.5 hr) drivers were twice as likely to want to have stopped earlier. Similarly they were not prepared to drive on for so long after the end of the driving day compared with half way through (Table 8).

Table 7

Frequencies with Which Drivers Indicated Driving Period To Be Too Short, Just Right, or Too Long

	Session	
	First half	Second half
Felt like driving on for longer	23	19
Felt period about right	16	11
Felt like stopping earlier	9	18

Table 8

Mean Time Drivers Felt Like Driving On (Hours)

		Session	
		First half	Second half
Early	Young	2.2	1.0
	Old	0.3	1.3
Late	Young	0.1	0.4
	Old	0.6	-1.1
All groups		0.9	0.4

In general old drivers were less prepared to drive on for longer (mean: 0.3 hr) than young drivers (mean: 1.0 hr) and late shift drivers were less prepared (mean: 0.0 hr) than early shift drivers (mean: 1.3 hr). These results are reflected by a contrast in the data in which the greatest preparedness to drive on was shown by young drivers after the first half of the early shift (mean: 2.2 hr) and the greatest reluctance by old drivers after the end of the late shift (mean: -1.1 hr).

Even after the end of the driving day there is a tendency for drivers on the early shift to feel like driving on for longer whereas on the late shift drivers are clearly much less inclined to feel like this. The result replicates an earlier finding for normal driving conditions (Fuller, 1978) and carries the implication that it is the timing and not the duration of the late shift that apparently makes it the more fatiguing.

Boredom. There were no effects of hours on boredom ratings (Friedman $X_{r}2 = 14.18$, $df = 9$, $p < .20$) although for all subjects there was a slight tendency to report increased boredom during each session half (Table 9). This tendency was independent of age of driver and driving shift.

Table 9

Feelings of Boredom: Mean Ratings Over Half Sessions (Rating of 1 = Very Bored, 5 = Not at All Bored)

	Periods of session half				
	1	2	3	4	5
First half	4.9	4.9	4.7	4.6	4.3
Second half	4.8	4.6	4.7	4.5	4.4
Combined	4.8	4.7	4.7	4.5	4.3

Awareness of Time Passing and How Quickly Time Seemed To Pass. In this analysis it was assumed that awareness of the passage of time and the feeling that it passed slowly would be positively associated with boredom. This seems to have been the case for ratings of awareness of time passing but not for ratings of how quickly it seemed to pass in which there was no variation over hours whatsoever (Table 10).

Table 10

Awareness of Time Passing and How Quickly It Seemed To Pass: Mean Ratings Over Half Session (Rating of 1 = Very, 5 = Not at All)

	Periods of session half				
	1	2	3	4	5
Awareness	4.4	4.3	4.2	4.1	4.0
How quickly	2.1	2.1	2.1	2.1	2.1

Irritation. Similarly for feelings of irritation, no relationship between hours of driving and ratings was found. However it is perhaps worth noting that older drivers on the late shift rated themselves as slightly more irritated than all other group/shift combinations (old mean: 4.4, others' mean: 4.8).

In general these results indicate slight increases in boredom over each half of the driving day, periods which were of course separated by a 30-minute meal break. But perhaps of more significance for this entire analysis of drivers' feelings and reactions to their driving is the evidence for decreased motivation at the end of the late shift, particularly amongst the older drivers. This seems to be entirely consistent with the evidence presented earlier suggesting a decrement in performance along with a concurrent decrement in capability.

Endocrine Changes

Pre and post driving serum levels of Cortisol and Testosterone and urine levels of Adrenaline and Noradrenaline for each half of the daily driving period were analysed for effects of samples, days, age, and shift. Apart from expected diurnal variation, no effects of the independent variables on Testosterone, Adrenaline, or Noradrenaline were found. However a significant age x shift interaction for Cortisol was observed ($F(1, 8) = 8.34$, $p < .05$) for which the relevant means are presented in Table 11. It may be seen that the expected decrease in level from early to late shift drivers did not occur for the older group. Although inspection of the results for pre-post samples revealed a decrease for the old late shift drivers in line with all other age-shift combinations, post driving Cortisol level for that group was the highest (old late mean = 6.9, others' mean = 4.4). This relatively elevated level for older drivers on the late shift may be tentatively interpreted as symptomatic of the onset of a biological coping mechanism and is consistent with an earlier finding for old, late shift drivers driving for prolonged periods but not in a convoy configuration (see Cullen et al., 1979). It is also consistent with the drivers' self report data in this study indicating particular performance, feeling, and motivational deteriorations for the late shift, old driver group.

Table 11

Cortisol Levels for Each Age-Shift Combination (μg%)

	Early shift	Late shift
Young	11.6	6.3
Old	8.4	9.4

SUMMARY AND CONCLUSIONS

Compared with the end of the early shift, drivers at the end of the late shift are beginning to describe symptoms of performance deterioration, drowsiness, and exhaustion and are more inclined to want to stop driving. These symptoms are slightly more characteristic of the older drivers for whom serum Cortisol levels are also relatively elevated. However in spite of this evidence the objective measure of performance used showed no increase in riskiness whatsoever (see Fuller, 1981). Indeed the performance change recorded, namely an increase in mean time headway at the end of the shift, implies a decrease in objective riskiness.

One interpretation of this apparent divergence in performance and self report data is that drivers responded to their awareness of incipient deterioration by increasing their following distance (for any given speed) and thereby effectively reduced the task demands with which they were faced. Thus increased time headway may be construed as a compensatory strategy for coping with the onset of fatigue. This possibility has been suggested in a theoretical review by McGlade (1970) and is consistent with an observation by Forbes (1959) that hazards such as right curves, downgrades, and low levels of illumination in tunnels all tend to increase time headway. An implication of this interpretation for driving safety is that where fatigued drivers are unable to compensate in this way (e.g., in high density traffic) they may be more vulnerable to both psychological and physiological strain and to risk of collision.

Lastly it should perhaps be reiterated that the evidence of this study supports the view that the effects of prolonged driving depend in part on _when_ that prolonged driving takes place rather than simply on its actual duration. This observation has obvious implications for driving practice and for legislation controlling hours of work for commercial truck drivers.

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APPENDIX E

ENDOCRINE STRESS RESPONSES OF DRIVERS IN A "REAL-LIFE" HEAVY-GOODS VEHICLE DRIVING TASK

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INTRODUCTION

Most commuters and many clinical studies have implicated motor vehicle driving as a potent stressor. The majority of these studies has sought to identify physiological changes which could be argued to be significant pathophysiological events or to represent precursors of specific diseases. Cardiovascular disease, hypertension and diabetes have been prominent in these considerations. Various hormones have been measured in drivers in earlier studies. These include 17-ketosteroids (17-KS) (Frost, Dryer & Kohlstaedt, 1951), 11-hydroxy-corticosteroid (11-OHCS) (Bellet, Roman & Kostis, 1969; Ravina, 1969) and of course, most frequently catecholamines or vanillylmandelic acid (VMA) (Schmid & Meythaler, 1964; Bellet et al., 1969; Ravina, 1969; Taggart, Gibbons & Somerville, 1969; McDonald, Baker, Bray & McDonald, 1969; Taggart & Carruthers, 1971; Kaatzsch, 1972; Somerville, 1973). Concern about a different source of human suffering and pathology, however, prompted the work reported here, namely research into the toxic and psychological aspects of road-traffic accidents.

A view that has gained general acceptance is that while research on driver behavior is well supported by theory and methods with regard to psychomotor performance variables, the whole issue of intra-subject "state variables" in drivers has lagged far behind the level of sophistication emerging in other, apparently unrelated, areas of psychobiological research. Many psychobiological factors are considered highly relevant to driver performance including interacting hormone profiles, pituitary-adrenal system hormone levels, attentional selectivity and stereotyped responding under high arousal stress, biological aging, especially in reactivity of organ systems to stressors, arousal decrease with age and the lag of subjective awareness of fatigue behind physiological indices and "photic driving" of hormone levels (Cullen & Fuller, 1978).

The factors which influence man as an information processing system, operating in the performance of complex tasks such as driving, are now more adequately viewed in the context of arousal theory (in which stress is a special case) and the many dimensions of coping cognitive behaviors. Physiological variables are both effect and cause in these systems. As deWied (1977) states:

One can expect therefore that alterations in the level of these hormones affect ongoing behaviour. Acquisition and extinction of conditioned behaviour indicate a behavioural adaptation to environmental changes. The influence of pituitary neuropeptides and glucocorticosteroids on acquisition and extinction of conditioned behaviour should therefore be considered in an adaptive framework. ACTH and related neuropeptides play a role in motivational learning and memory processes while corticosteroids facilitate discrimination and thereby the elimination of non-relevant responses. (pp. 15-16)

This summary indicates a dramatic change in viewpoint where these hormones are no longer perceived merely as response variables but as powerful intervening variables in the cognitive processes which represent coping. Hennessy and Levine (1978) have recently presented a comprehensive psychoendocrine model for these processes in stress, arousal and the pituitary-adrenal system.

Gonadal hormones, especially testosterone, have been found to be sensitive to stressors. Clearly, prolonged and onerous driving can be viewed as demanding sustained high levels of arousal and/or stress. This raises the question of the effect of such experiences on levels of testosterone and the possibility of using measures of this hormone as an indicator of driver physiological state. Earlier work of Parry (1968) suggested that the concomitance of anxiety and aggression in drivers lead to markedly increased accident risk. This further enhanced the attractiveness of testosterone as a variable, particularly in view of its rather controversial status as a factor in aggressive behavior. The relationships of testosterone and glucocorticoids seem therefore to be relevant. A recent study by Davison, Smith and Levine (1978) reports further on these issues in an experiment conducted with parachute troops in early training. Prolactin, because of its role in testosterone metabolism through the induction of some of the required enzymes and its probable role in the maintenance of a testosterone precursor pool, was included as a variable in this study. A similar role in cortisol metabolism has been suggested for prolactin (Horrobin, 1973). In man, elevated prolactin levels have been found in response to stressful stimuli, e.g., medical or surgical interventions (Noel, Suh & Frantz, 1971; Noel, Suh, Stone & Frantz, 1972). The literature on catecholamine responses in stress and various strenuous performance tasks is immense. The contributions of Levi (1972) and of Frankenhaueser, Nordheden, Myrsten and Post (1971) in this field are most notable. There is considerable evidence to support the view that adrenalin and noradrenalin fulfill different roles, under certain conditions in the coping repertoire (Frankenhaueser et al., 1971; O'Hanlon & Horvath, 1973).

Road traffic accidents constitute a significant social and economic cost to the community. It is vital that systematic studies be undertaken to identify those factors which are causally related to accidents and to evaluate the consequences of the effort demanded of the driver in maintaining an accident-free performance under adverse conditions. Although to date no consistent relationship has been found between various stresses on drivers and their accident involvement, individual differences in response to the same stress may be crucial in determining whether or not driving is seriously impaired. One such difference which has been identified is in apprehension, which has been shown to discriminate between accident-free and accident-involved drivers. However, new and potentially more powerful measures of individual differences in response to stress are now available in the form of assays of hormonal levels from microsamples of blood. The occurrence of particular hormone profiles in stress situations may have critical effects on the safety of driving performance. Endocrine measures of response to stress have an additional value in that they provide a reliable and meaningful index of the physiological and psychological "cost" (e.g., in effort) to the driver of maintaining an adequate performance under adverse conditions. Such considerations may be highly relevant not only to accident riskiness but also to the long-term effects of driving on professional drivers of commercial heavy goods and public service vehicles. It was in order to elucidate these issues that the present work was undertaken.

METHODS

Subjects

Subjects (S) were volunteer professional heavy goods vehicle (HGV) drivers, recruited through the appropriate Trades Union. Each S was paid $175 for participating in the project. Two different age groups were selected with mean ages of 28.8 yr (s.d. = 2.9) and 41.3 yr (s.d. = 4.1) respectively. There were 12 subjects in all, 6 in each age group (*n* = 12).

Driving Task

Each S was required to drive an instrumented 7-ton Bedford rigid van-type truck for 11 hr on each of 4 consecutive days over a preselected route of approximately 300 miles. The route consisted of two loops out of and returning to Dublin. Driving was continuous over 11 hr except for a 30 min meal break after 5½ hr and one 5 min break during each of the 5½ hr sessions for refueling of an AC generator which powered the research instrumentation. S's in each age group were assigned at random for the duration of the experiment to one of two driving shifts which started either at 09.00 hr or 15.00 hr. These two shifts were selected, after a previous survey of the working conditions of HGV drivers as being the two most frequently operated commercial shifts.

Endocrine Measures

Blood samples (20 ml) were taken from each S immediately before and after each 11 hr driving session on the 4 consecutive driving days and at the appropriate first and second sampling times on Day 1 which was a non-driving day. In addition a daily 11½ hr urine sample was collected during the session and over the appropriate period during Day 1. Blood samples were assayed for serum cortisol, serum testosterone, serum prolactin and caffeine. Urine samples were assayed for adrenalin and noradrenalin. Assays were carried out in the Psychoendocrine Unit of the Department of Psychiatry, University College, Dublin at the Biological and Medical Research Institute, St. James's Hospital, Dublin 8.

Performance Measures

Several performance variables were continuously measured and recorded throughout each driving session. These are not of relevance here and the data have been reported in detail elsewhere. The main measures used were (1) Mean time headway: This was a measure of the headway or time-speed factor with a vehicle in front of the experimental HGV in following situations. This measure has been found to correlate highly with measures of riskiness in driving. A new technique for continuous monitoring of this measure was developed and involved the use of two video tape recorder (VTR) cameras and the application of the parallax principle as in camera rangefinders. (2) Applications of the vehicle foot-brake. (3) Questionnaire: At the start of each session S's were administered a questionnaire which rated sleep duration and quality for the previous night, any consumption of alcohol, drugs and medicines and his fatigue state. At the end of each 5½ hr driving session, S's were asked to rate their performance, motivation and fatigue on a five-point scale together with other subjective ratings. The short form of the Eysenck Personality Inventory (EPI) was administered to each S on Day 1.

Procedure

Each S attended the Psychoendocrine Unit, St. James Hospital, Dublin at either 09.00 hr or 15.00 hr for 5 consecutive days. On Day 1, a 20 ml blood sample was taken. S was instructed in detail on the complete procedure for the remainder of the experiment. He was asked to complete the EPI (short form) and he was also given a brief familiarization with the experimental vehicle. He was then given a sample container to collect his urine for the next 11½ hr and asked to return to the Unit for his second blood sample at either 20.30 hr or 02.30 hr (depending on his shift allocation). Thus Day 1 was used both to familiarize subjects with the experimental procedure and to obtain reference base-line values for the endocrine analysis. On Days 2-5 the procedure was largely the same as for Day 1 with the major additional requirements that S carry out the driving task described earlier and complete the various questionnaires. On Day 5 the subject was required to complete an additional questionnaire which related to his reactions to the experiment as a whole including the blood-sampling experience.

Experimental Design and Statistical Method

The independent variables in this study were age (2 levels), shift (2 levels), day of driving (4 levels) and pre-post sample (2 levels). The general design therefore is a 2 x 2 x 4 x 2 factorial analysis of variance with repeated measures on the last 2 factors. The main dependent variables, in the portion of the study reported here, were the endocrine measures, namely those for blood cortisol, testosterone, prolactin (with caffeine as an additional measure) and urine adrenalin and noradrenalin. Additional subsidiary variables were provided by S's subjective evaluation of performance, fatigue and motivation and by EPI ratings. Control day (i.e., Day 1) values for cortisol, testosterone and prolactin were submitted to a three-factor factorial analysis of variance with age (2 levels), shift (2 levels) and pre-post blood samples (2 levels) as main factors and repeated measures on the last factor. Driving days values (Days 2-5) for cortisol, testosterone and prolactin were submitted to a four-factor factorial analysis of variance with age (2 levels), shift (2 levels), days (4 levels) and pre-post samples (2 levels) as main factors and repeated measures on the last two factors. Control day and driving days data for adrenalin, noradrenalin and caffeine were submitted to similar analysis of variance.

RESULTS

The findings for each hormone are presented separately. No significant effects were found for adrenalin, noradrenalin or caffeine.

Cortisol

For the non-driving day the only significant result was a drop in cortisol levels from first to second sample for both shifts [$F(1,8) = 26.28$, $p < 0.001$]. For driving days a similar significant main effect was found [$F(1,8) = 77.35$, $p < 0.001$]. Both these are shown in Fig. 1 where the time of day of pre- and post-driving samples and the equivalent for the non-driving day are indicated. The overall mean cortisol level for the non-driving day was 12 ± 4.8 μg%. This was not significantly different from the overall mean cortisol level for the driving days which was 9.8 ± 2.5 μg%. There was a correlation of -0.88 ($n = 12$) between mean cortisol level on the non-driving Day 1 and the mean change from Day 1 in cortisol level for driving days, indicating that subjects with higher levels on the first day tended to show a drop in level while those with lower levels tended to show an increase. Analysis of variance for cortisol levels on driving days gave a second significant main effect for days on task. There was a tendency for levels to fall over the first 3 days with a slight rise on the last day. (Means = 11.15, 10.41, 8.47, 9.01, $F(3,24) = 4.23$, $p < 0.05$). Interpretation of these results was complicated by the large number of significant interactions, the most significant of which was the four-way interaction among all factors [$F(3,24 = 5.06$, $p < 0.01)$]. Figure 2 shows cortisol as a function of age, shift and pre- and post-sample. For the younger drivers the cortisol levels fell off at about the same rate for both shifts. For older drivers, however, there was a very large drop on the early shift while on the late shift the decrease was not significant. To take into account the interaction with days, Table 1 gives the day by day cortisol levels for the four groups considered in Fig. 2. The interaction with days was present only for the early shifts. There was a fall-off in pre-driving cortisol levels over days on task for the early shift in younger and older drivers alike. No trends over days were evident for the late shifts.

Testosterone

For the non-driving days there were no main effects found for testosterone. There was a significant interaction, however, between shift and sample time [$F(1,8) = 11.1$, $p < 0.05$]. Testosterone levels fell over the early shift but increased over the late shift. For driving days this interaction was no longer present but a significant main effect was found for pre-post samples [$F(1,8) = 9.59$, $p < 0.05$]. Testosterone levels again fell

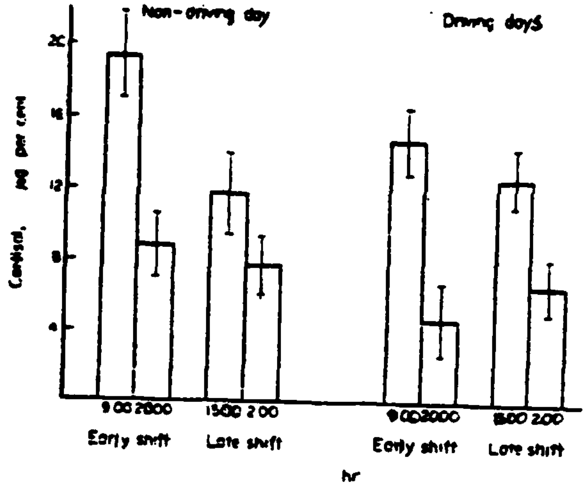

Figure 1. Mean (±S.E.M.) cortisol levels for pre- and post-samples of early and late shifts on non-driving day, and driving days (n = 6).

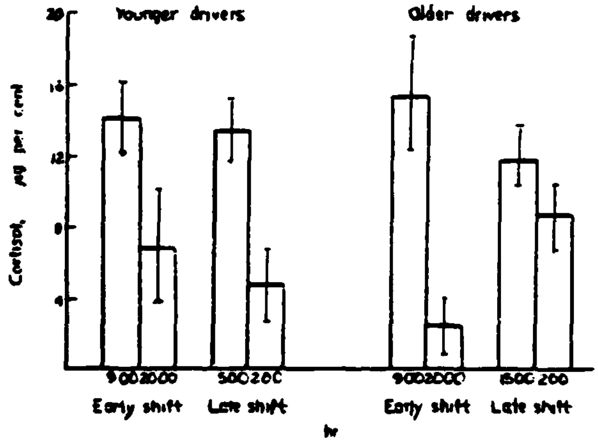

Figure 2. Mean (±S.E.M.) driving days cortisol levels for pre- and post-samples of early and late shifts for younger vs. older drivers (n = 3).

over the early shift but there was no change in level over the late shift. Both these findings, for non-driving day and driving days, are shown in Figure 3.

Table 1

Cortisol Values for Groups by Pre-Post Samples

		Pre-driving	Post-driving
Young			
Early shift	1	16.67	9.03
	2	13.43	11.13
	3	13.73	4.93
	4	12.90	2.23
Late shift	1	13.83	6.87
	2	14.90	3.83
	3	10.80	3.63
	4	14.30	5.13
Old			
Early shift	1	20.30	2.50
	2	15.77	0.50
	3	13.47	2.63
	4	12.57	4.97
Late shift	1	12.67	7.30
	2	12.10	11.63
	3	11.73	6.87
	4	11.57	8.40

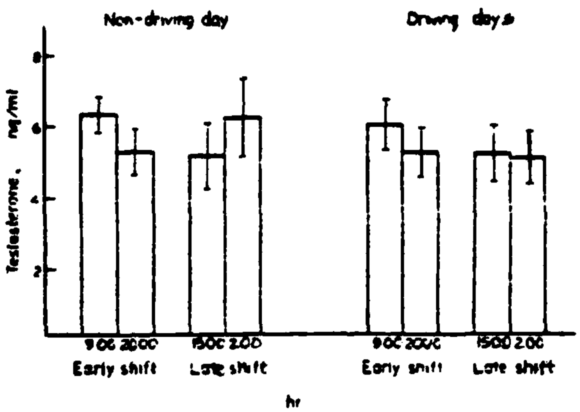

Figure 3. Mean (±S.E.M.) testosterone levels for pre- and post-samples of early and late shifts on non-driving and driving days ($\underline{n}$ = 6)

Prolactin

On the non-driving day no significant findings emerged for prolactin. Similarly on the driving days no significant effect was found. However, the overall mean for prolactin (i.e., for all subjects under all conditions) showed a significant drop from non-driving day to driving days. Overall mean prolactin for the non-driving day was 9.6 ng/ml ± 6.7 and for the driving days was 7.6 ng/ml ± 5.4. Every driver showed this drop in prolactin except for one subject who showed a miniscule increase of 0.1 ng/ml.

Performance

Data on performance must be discussed elsewhere as a separate study. However a global rating for overall performance in terms of a type of "safety quotient" was derived. This was correlated with endocrine and personality measures. A negative correlation was found between performance and a number of cortisol parameters. High levels of cortisol in pre- and post-samples on the non-driving day and high levels for the pre-driving sample on experimental days (driving days) were significantly associated ($r = -0.5$), with low performance ratings.

Personality

Personality scores from the EPI (Eysenck Personality Inventory) also correlated significantly with the mean cortisol levels on the non-driving day but not on the driving days. Personality factors scored were extraversion and neuroticism. Extraversion correlated positively with cortisol whereas neuroticism correlated negatively. Extraversion and neuroticism were not correlated, as Eysenck claims, but neither were personality and performance measures.

DISCUSSION

The failure of this study to show significant findings for adrenalin and noradrenalin was surprising. It may, perhaps, be explained by reference to previous findings of Taggart et al. (1969), where catecholamines were not increased in coronary heart disease patients after a city driving task whereas racing motor-car drivers showed a considerable increase in noradrenalin immediately after racing (one driver also showed an increase in adrenalin). On the other hand, Schmid and Meythaler (1964) showed raised VMA levels for both city drivers and their passengers. This variety of effects may reflect differing cognitive sets in the groups studied. Perhaps driving for the HGV driver represents a form of coping which differentiates the hypothalamic-pituitary-adrenal system from the neuro-medullary system.

The cortisol data gave a large number of significant findings. The most consistent was a decrease in cortisol levels from beginning to end of an 11 hr shift period. Since there was a tendency for cortisol to show an overall decrease over the four samples taken within a 24-hr period, the influence of circadian effects must be considered. The overall decrease was most evident for the non-driving day; however, the magnitude of the cortisol levels for the earliest sample on the non-driving day (20 μg %) was outside normal values and indicates an elevation probably due to the initial blood-sampling experience itself. The level of this 09.00 hr sample fell consistently over days, so that by the fifth day it had fallen to the level of the pre-driving sample of the late shift (15.00 hr). Thus, on the fifth day, measures showed no evidence of either circadian or sampling influences. The fact that an elevation related to days was found only on the pre-samples of the early shift is noteworthy and suggests a diurnal factor in pituitary-adrenocortical responsiveness. The fall in cortisol levels on driving days for both shifts would confirm that one is dealing here with experienced drivers for whom the task was not a marked stressor. Indeed, the contrary seems to have been the case in some conditions; cortisol levels fell so low for the older drivers on the early shift that driving seems to have been a very arousal-reducing activity for them. This might be compared with the reduction in cortisol levels found with different types of consummatory behaviors in animals (Levine, Weinberg & Brett, 1979).

Testosterone and prolactin findings seem to provide information about the physiological "cost" incurred by the type of work involved in HGV driving. It is proposed to continue these studies in a new population of balanced groups of young and old subjects under more strenuous convoy conditions.

A Note on More Recent Additional Data

Since the study described in this paper was completed, a further study of 6 subjects (3 young and 3 old) on a late shift schedule was carried out. This was a similarly designed experiment except that there was an increase in the strenuousness of the task due to the introduction of a leading vehicle and requiring additional following. The interesting new data sustained the original findings for cortisol. However, the findings for testosterone were different in that the rise in level of the second sample on the control day did not take place. No obvious explanation for this arises. However, the age distribution of the older drivers in this new group of subjects was much wider. Ideally a narrower range of age should have been maintained. On the other hand, with the pooled data for the two studies, prolactin showed a marked pre- to post-difference on the control day which was not present on driving days. However, as only late shift subjects were studied the data are vulnerable.

In all of this work we must record our great debt of gratitude to Dr. Austin Darragh and his staff in the Biological and Medical Research Institute for advice and biochemical assays. Assistance in this research was provided under grant DAERO-76-G-042 from the U.S. Army Research Institute for the Behavioral and Social Sciences, through its European Liaison Office in London, England. The opinions expressed are those of the authors and do not necessarily represent those of the U.S. Army.

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APPENDIX F

DETERMINANTS OF TIME HEADWAY ADOPTED BY TRUCK DRIVERS: A REASSESSMENT

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ABSTRACT

The results of a field experiment on the effects on time headway of prolonged driving in a continuous convoy situation were analysed to explore the distribution over time of very short (<1.0s) and very long (>2.5s) headway values.

Short headways were associated with periods of driving in which unanticipated relative deceleration in the leading vehicle could be discounted. Long headways were associated with the onset of driving, the end of each 5.5-hr driving period, and driving in darkness.

It was suggested that drivers modify time headway so as to avoid raising the risk level of their performance beyond some subjective criterion level. Thus where task difficulty is relatively high or performance capability low, drivers tend to increase headway and vice-versa. This conceptualisation may be generalisable to aspects of driving other than adopted headway such as the selection of vehicle speed and decisions to overtake.

INTRODUCTION

In an earlier report by the author (Fuller, 1981) data were presented on the effects of prolonged driving on samples of time headway adopted by truck drivers in convoy. That report used average hourly time headway as a main dependent variable and revealed no evidence of increased performance riskiness over time (in the sense of a decrease in elected headway) despite the requirement on drivers to drive for 11 hours per day for 4 consecutive days and with only one 30-min meal break each day during the driving task.

However one weakness of using average hourly time headway as a performance measure, particularly with large numbers of observations per hour as in that study, is that acute episodes of close following are not represented by the mean value unless they are more or less characteristic of performance over the entire hour, a somewhat unlikely event. One way of tackling this shortcoming is to examine the distribution over time of very short headways and this report presents just such an analysis.

METHOD

The measure of performance used was the frequency distribution of very short headways adopted by drivers over time in a prolonged HGV convoy driving task.

Details of the task and procedures employed have been published earlier (Fuller, 1981) but in brief 12 volunteer professional army drivers were required to drive an instrumented 7-ton Bedford rigid van-type truck for 11 hours on each of 4 consecutive days over a preselected route of approximately 300 miles, which was repeated on each day. Driving was continuous except for a 30-min meal break after 5½ hours and one 10-min break during each session. Subjects were allocated to either a young group (mean age 22.7 years, SD = 1.0) or old group (mean age 33.5 years, SD = 4.7) and to an early shift (09.00 hours onset) or a late shift (15.00 hours onset). Drivers were instructed to follow continuously a leading Volkswagen 15 cwt van and time headway was sampled when appropriate at approximately 18-sec intervals using a closed circuit television system (see Fuller et al., 1980).

Since mean aggregate time headway in the original study was 1.76 s with SD = 0.57, approximately 10 percent of following samples would have yielded a time headway of less than 1.0 s, assuming an approximation to a normal distribution. The value of less than 1.0 s was therefore selected as the cut-off point to define very short headways and the frequency of such headways was analysed for each half hour of driving. It is notable that the criterion value of less than 1.0 s is 1.0 s lower than the recommended minimum headway and represents a following distance of less than 60 feet at 40 mph.

RESULTS AND DISCUSSION

Two analyses were initially carried out on the frequency data, one for the absolute frequency of very short headways in each half hour of driving and one for the proportion, expressed as a percentage, of very short headways in each half-hour sample. The first measure represents the actual experience of close following for the drivers in this study, whereas the latter measure takes account of sample size variation attributable to the varying and uncontrollable road conditions obtaining for each half-hour sample. The statistical design used in each case was a 2 x 2 x 22 factorial Anova with main factors of shift (two levels), age (two levels), and half-hour sample (22 levels), with repeated measures on the last factor and n (cell) = 3. Data for days were pooled because the original time headway means analysis had revealed no evidence for a relevant days x hours interaction. This procedure provided a much more reliable sample for hours. Nevertheless, it is worth noting that there was a gradual increase in the frequency of very short headways over days with half-hour mean values as follows: Day 1--3.8, Day 2--4.4, Day 3--4.8, Day 4--5.6.

The *Anova* for absolute frequencies of very short headways yielded two main effects for shift ($F(1,8) = 18.28$, $p < .01$) and for half-hour sample ($F(21,168) = 2.21$, $p < .01$). There were no other significant main effects or interactions. Sample means for each shift were early shift: 4.0 per half hour and late shift: 1.3 per half hour. Analysis of the means for each of the 22 half-hour samples revealed relatively low values for samples 1, 7, 11 and high values for samples 3, 4, 13, 14 (see relevant curve in Figure 1). The value for sample 1 was significantly lower than for samples 3, 4, 13, 14; sample 11 was significantly lower than for samples 4 and 14 and finally sample 7 was significantly lower than sample 14.

The *Anova* for percentages of very short headways in each half-hour sample revealed only a main effect for shift ($F(1,8) = 19.06$, $p < .01$) and a first-order interaction between shift and age ($F(1,8) = 6.72$, $p < .05$) indicating that the shift effect was not independent of age group of driver. On the early shift 12.8 percent of observations were of very short headways and this value dropped to 4.4 percent on the late shift. However, analysis of the shift x age interaction showed that the shift effect was reliable for the old group only (see Table 1). Although this analysis revealed no significant effect for half-hour sample, it may be seen from the relevant curve in Figure 1 that a similar pattern emerged to that for the absolute frequency data. It may also be noted that the distribution over time of short headways in steady state following, where the following driver is in a "coupled" relationship with the leading vehicle and is neither braking nor closing on it, a very similar pattern emerged as for the aggregate data (Pearson $r = 0.95$, $df = 20$, $p < .001$).

Table 1

Percentage of Headways of Less Than 1.0 S for Each Shift-Age Combination

	Young	Old
Early shift	8.7	17.0
Late shift	5.2	3.6

These results indicate that very short headways were relatively predominant in the early shift (particularly for older drivers) and, independently of shift, reached peaks around samples 3-4 and 13-14. Sample 1, on the other hand, was associated with the lowest proportion of very short headways.

In an exploration of the implications of these results a comparison was made with the findings of an earlier study in which the distribution of very short headways occurring in natural and spontaneous following episodes was reported (Fuller, 1978). That study had used the same experimental HGV as the present study, the same driving shifts and routes, and had recruited professional HGV drivers as subjects. A comparison of the results for both studies may be seen in Figure 2. Because the earlier study employed samples of 1-hour duration, the data for the present study were reanalysed on that basis.

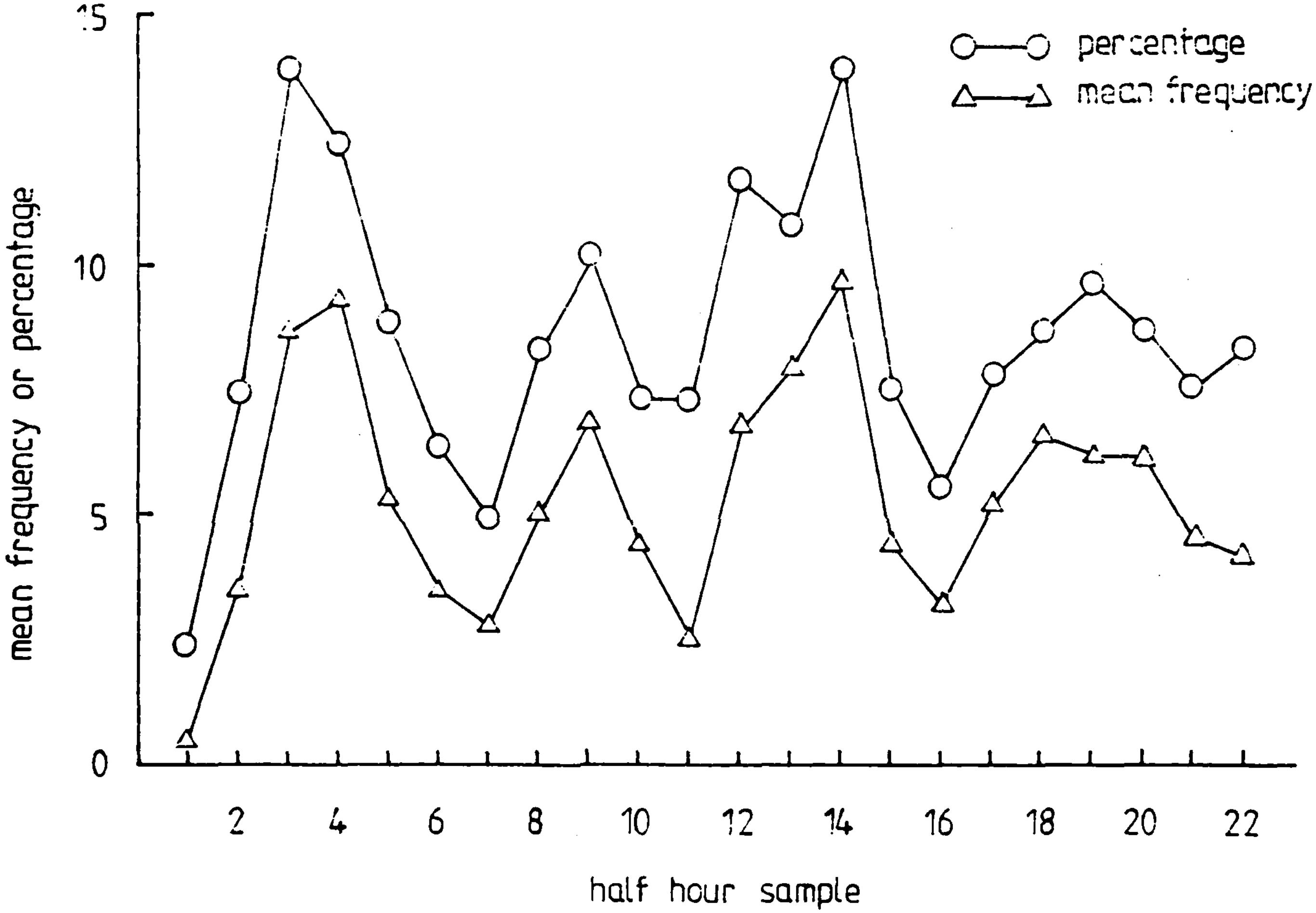
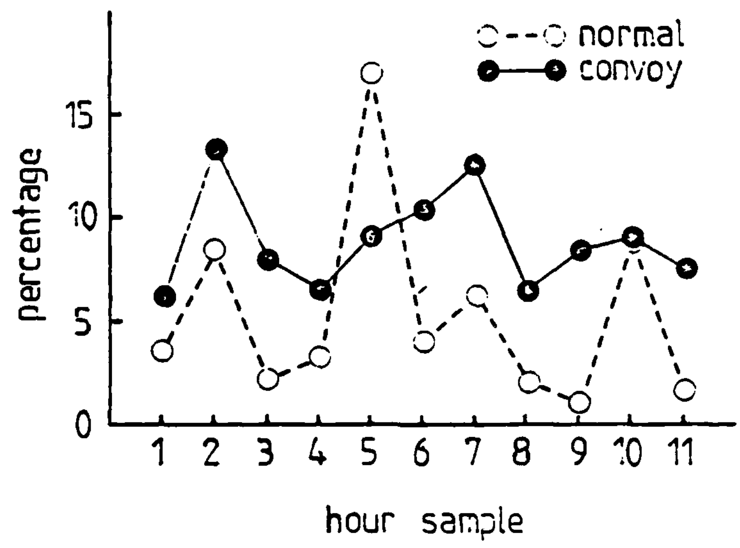


Figure 1. Mean frequency and percentage of time headway values of less than 1.0 s for each half-hour sample.



<u>Figure 2</u>. Percentage of time headway values of less than 1.0 s for each hour of driving under normal and convoy conditions.

Inspection of Figure 2 indicates that, with the exception of the sample for hour 5 for which there was a marked increase in the proportion of very short headways in the data for normal driving, the correspondence between the patterns for convoy and normal driving is quite close (for all data Pearson r = 0.40, df = 9, $p < 0.15$ and excluding hour 5, r = 0.67, df = 8, $p < 0.02$).

Because of the more or less fixed relationship between hour of driving and particular part of the route being driven, it was noted in the earlier study that periods of short headway coincided with periods of rural trunk road driving in which traffic flow was uninterrupted. Under such conditions drivers could predict that sudden, unexpected relative deceleration in the leading vehicle would have such a low probability that it could be discounted. Thus the preferred explanation for the occurrence of chronic periods of short headway following was that they occurred precisely when drivers could make such a prediction.

Perhaps a similar interpretation may be applied to the results of the present study of convoy driving with the evidence that periods of short headway again occurred where drivers were able to assume that instantaneous and unexpected relative deceleration in the leading vehicle would not take place.

Such an interpretation is of course consistent with the significant shift difference which revealed that drivers were about three times more likely to follow closely during the early shift compared with the late shift for which about 80 percent of driving was in darkness. It is also consistent with the observation that the overall pattern of short headways was typical only for the early shift and daylight part of the late shift but not for night driving (see Figure 3).

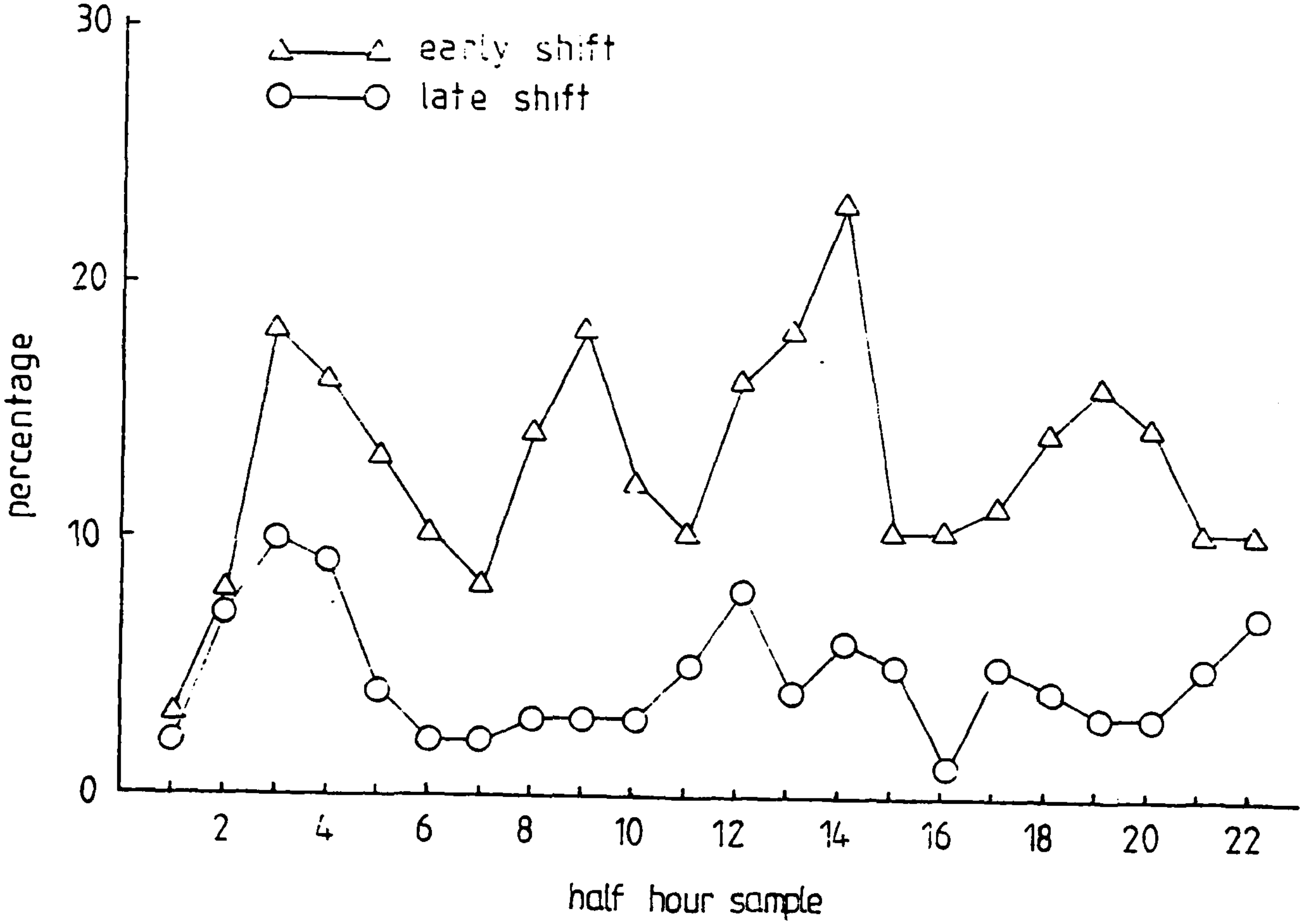


Figure 3. Percentage of time headway values of less than 1.0 s for each half hour of driving and for each shift.

The above interpretation of the distribution over time (or as it is argued, place) of short headways raises the question of what very short headways actually imply from the point of view of performance safety or its converse, riskiness. At the outset of the experiment under discussion it was assumed that decreases in time headway could be unambiguously interpreted as increases in riskiness: the shorter the headway the less time a driver had to react to avoid a potential rear-end collision. Under two possible sets of circumstances this assumption still holds: That is when predictions that instantaneous deceleration will not take place are incorrect and/or when a driver's ability to detect and respond to sudden relative deceleration in the leading vehicle remains constant or actually deteriorates. Under these circumstances shorter headways must imply greater risk. On the other hand from the evidence drivers appear to adopt short headways particularly when it is highly unlikely that the leading vehicle will decelerate and so no real increase in riskiness is necessarily implied. Furthermore, the behavior of close following may be associated with periods during which the driver's performance capability, particularly in the detection of and reaction to leading vehicle deceleration, is at an optimum. On this analysis a longer time headway could in actuality be the more risky, if the driver's capability has become sufficiently impaired. Short headways then, rather than necessarily implying increased riskiness, specifically represent an increase in the demands on the driver. No enhanced risk will obtain if the leading vehicle does not decelerate or if the capability of the driver is raised to meet the increased demand. On the other hand, close following presumably demands a heightened state of readiness in the driver, rather like being chronically in the interval between the "ready" and trigger stimulus in a reaction time experiment. Under such circumstances, even though there may be no observable change in performance, the onset of fatigue may occur more rapidly.

One implication of this analysis is that if shorter headway means an increased demand on the driver, necessitating him to react more quickly should the leading vehicle suddenly decelerate, the selection of a relatively long headway may indicate a driver's wish to lower the demands on himself, presumably because he is either not motivated or sees himself as not being capable or both. This may be particularly the case in a convoy situation where the driver is required to follow continuously another vehicle.

In pursuance of this line of thought an inspection of the distribution over time of relatively long time headway values was carried out. Long headways were defined as greater than 2.5 s and again assuming a normal distribution approximately 10 percent of samples would have been in this category. This criterion is equivalent to a distance of over 146 feet at 40 mph and is 0.5 sec longer than the recommended minimum headway interval. In Figure 4 may be seen a graph of the percentage of time headway values of more than 2.5 s for each half-hour sample. Long headway values were strikingly characteristic of samples 1 and 2 and to a lesser extent samples 11 and 22. A low frequency of long headway values was particularly associated with samples 4 and 14. This distribution suggests the possibility of a complementary relationship to that for very short headways, to some extent confirmed by a Pearson product moment correlation coefficient for the two sets of data of $\underline{r} = -0.52$, $\underline{df} = 2$, $\underline{p} < .01$ and an equivalent value for steady-state following data alone of $\underline{r} = 0.37$, $\underline{df} = 20$, $\underline{p} < .05$. Long headway intervals tended to occur at periods of time when very short headways were

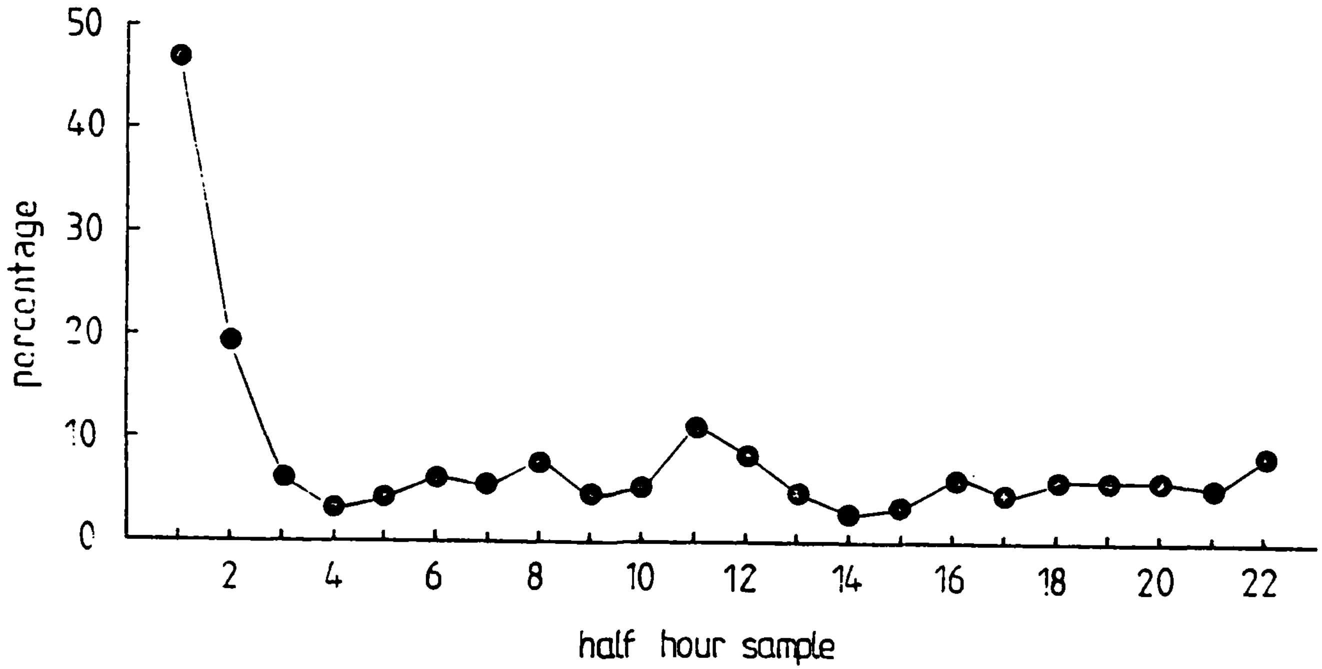


Figure 4. Percentage of time headway values of more than 2.5 s for each half-hour sample.

relatively infrequent. Although this sounds somewhat tautologous, it is not necessary for short and long headway intervals to be related in this way.

If the adoption of a long headway reflects the driver's wish to reduce the task demands on himself, then it may be concluded that this occurs in a dramatic way for the first hour of driving but also increases slightly in the last period immediately before a main break in driving (samples 11 and 22). It is tempting to interpret the first of these effects as one of adjustment to the demands of close following in convoy driving, a form of warm-up effect, and the latter as an adjustment by the driver to impairment in his own capability. Consistent with this last interpretation are driver's ratings of feelings of drowsiness and exhaustion, both of which showed increases toward the end of each main period of driving (see Figure 5). A Friedman test revealed a significant effect for hours on drowsiness ratings (X_{r2} = 28.78, df = 9, $p < .001$) but the results for exhaustion ratings just failed to reach the criterion level (X_{r2} = 14.13, df = 9, $p < .10$).

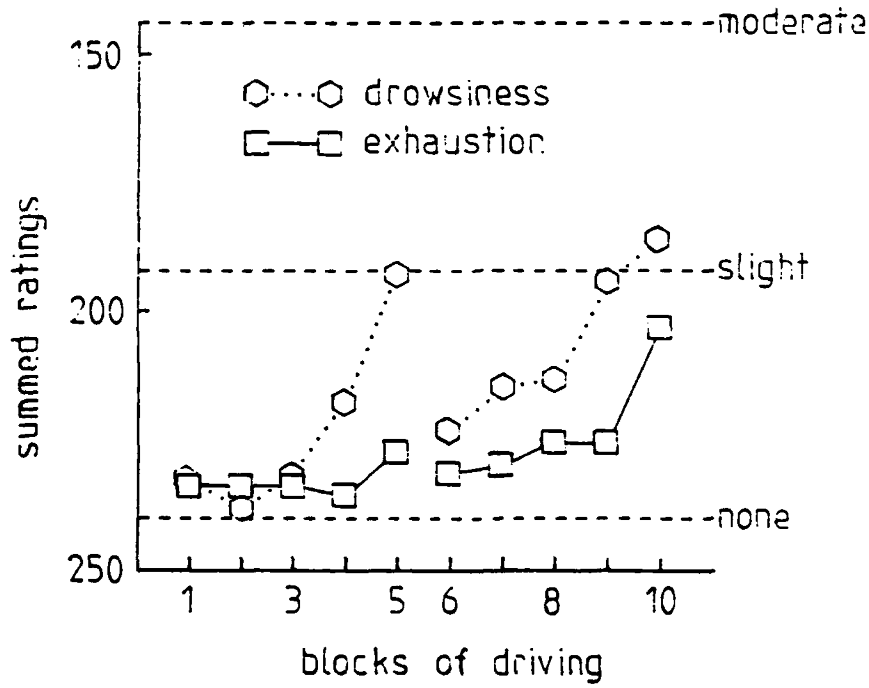


Figure 5. Summed ratings for drowsiness and exhaustion for each period of driving. (For ease of rating each half-shift was divided into five equal blocks. Ratings were on a five-point scale.)

Although the pieces of this jigsaw hang together somewhat tentatively, what emerges is the following picture. Early on in convoy driving, drivers tend to sit back from the leading vehicle and seem to need time to adjust to the continuous close-following requirement. Periods in which very short headways occur are characteristically associated with daylight hours and during daylight hours with parts of the driving route in which sudden, unanticipated deceleration in the leading vehicle can be discounted. On the other hand, toward the end of each 5½-hr period of driving, drivers are less likely to adopt a very short headway and more likely to adopt a relatively long one, this latter perhaps representing a safety-oriented response to felt increases in drowsiness and exhaustion. What the driver may be said to be doing here is trying to match varying task demands with an appropriate level of performance in an attempt not to increase the subjective riskiness of his behaviour beyond some acceptable level. Thus when his capability is relatively low, such as at the onset of the convoy driving task or when suffering later from drowsiness or when driving in darkness, he can reduce task demand by following at a greater distance and thereby avoid an increase in riskiness. Similarly, where the task demand is automatically lessened, such as when unexpected leading vehicle deceleration may be discounted, the driver can follow more closely without any increased riskiness, a strategy which otherwise could only be interpreted as more risky. In sum, the driver can select a headway which enables him to match his current capability to the prevailing demands of the task.

This same conceptualisation would seem to apply just as readily to vehicle manoeuvres other than headway maintenance such as the selection of a particular road speed or decisions to overtake. Normally the task of driving is self-paced, which implies that a driver can avoid increasing his level of risk either by changing the level of task demand or by changing the level of his performance or both. Situations in which task demand cannot be easily altered, such as when a driver is tied to a time schedule, and in which there is simultaneous decrement in performance capability stand out as notable candidates for enhanced accident risk. Although drivers in this study were required to maintain close following in a constant convoy configuration, there was sufficient flexibility in the task demands to enable them to compensate for fluctuations in performance capability and thereby avoid any accident or near-accident involvement.

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APPENDIX G

SELF-PACING AND TRUCK DRIVING PERFORMANCE: A PRELIMINARY STUDY

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ABSTRACT

The effects on truck drivers of withholding information about commencement of driving, duration of driving periods, and end of working day were studied using 12 Army drivers who each drove an instrumented 7-ton truck as the second of a two-vehicle convoy for 4 consecutive days. Dependent variables were performance safety (time headway and its variability), drivers' ratings of performance, fatigue, and motivation, and endocrine responses.

No effects of the information variable were found on either performance or endocrine responses and only slight differences were observed in self-ratings. Long headways were associated with the beginning and end of the driving day and the latter was also associated with slight increases in exhaustion, drowsiness, and daydreaming.

These results were interpreted to reveal that the uninformed drivers tacitly set task expectations generally in excess of actual requirements and that drivers adjusted to perceived decreases in capability by increasing headway.

INTRODUCTION

In 1970 the U.S. Bureau of Motor Carrier Safety investigated 286 commercial vehicle accidents and attributed 39 percent of these to the driver being either asleep at the wheel or inattentive. In the same year in the U.K. a marked decline in accidents involving heavy goods vehicles was recorded after the reduction of maximum permitted hours driving per day to 10. In 1972, Harris and Mackie found that in a haulage and bus company real accident rates were significantly higher than expected after 7-10 hours of driving.

This evidence is consistent with the hypothesis that there exists a relationship between prolonged HGV driving and accident risk. Nevertheless, it is difficult to find confirmatory evidence in the experimental literature.

Leaving aside studies of performance changes over time which simply cannot be interpreted in terms of accident riskiness, some research has revealed improvement in safety over time (e.g., Brown, 1965), no change (e.g., Dobbins, Teidman, and Skordahl, 1965; Brown, 1967a; Fuller, 1978a) or slight impairment in functions which are possibly critical for safe driving (e.g., Brown, 1967b; Kaluger and Smith, 1970; Brown, Tichner, and Simmonds, 1970; Lisper, Dureman, Ericsson, and Karnisson, 1971). Of these studies only one was directly concerned with drivers of heavy goods vehicles and none has demonstrated a clear relationship between prolonged HGV driving and accident risk.

A predominant and sometimes tacit conceptualization of the effects of prolonged work on fatigue is that after some period of sustained effort a progressive deterioration occurs marked by characteristics such as decreased effectiveness and efficiency and increased variability and error rate. However, it could be argued that fatigue effects are not necessarily cumulative and that the onset of impairment may be relatively sudden and severe. It is suggested that this might happen in the context of the relationship between task expectations and what actually goes on to occur.

It has long been known that in simple mental tasks rate of work is a function of the anticipated duration of the task (Krueger, 1937; Barmack, 1939; Forrest, 1958) and that energy expenditure may be regulated according to expected task demands (e.g., Ward, 1950; Jarrard, 1960). In a brief review of some of this evidence, Welford (1968) concluded that the experimental results were complementary to the well known fact that athletes pace their performance from the beginning of a race according to the distance to be covered (or duration of running) to avoid premature onset of exhaustion due to overexertion in the early stages. This self-pacing phenomenon appears to be founded on two basic assumptions, first that there is some limit to the effort available to carry out a particular task and second that this effort needs to be managed so that it is sufficient for the duration of the task. Normally one thinks about self-pacing in relation to self-control of the <u>rate</u> of work but this in turn must be related in some way to the total amount of effort available.

In the normal work situation, of course, the worker knows for how long he must work and usually how hard he must work and is therefore well able to manage his effort appropriately, presumably avoiding undesirable fatigue effects. But what happens if, because of irregular demands, he simply cannot manage his effort in this way or, having worked for the expected duration, further demands are made on him?

That even a slight increase over expected demands may have a significant effect on motivation was dramatically demonstrated by one driver in an earlier study carried out by the author (Fuller, 1978b). After the driver's daily 11-hour run he was asked just to drive around the block so that some recording equipment that had developed a minor fault could be checked. Normally a mild, quiet, and affable individual, he suddenly became verbally aggressive, loud, and uncooperative.

That drivers are able to manage their effort appropriately over several experimental runs of 11 hours was also evidenced by their responses to the question: "Would you like to have driven on for longer or stopped earlier?" Although 11 hours was an unusually prolonged driving period, the most frequent response to that question was that the task was "just about right." Drivers rarely experienced a desire to drive on for longer but at the same time they weren't particularly concerned to stop earlier either.

In studies of the relationship between "fatigue" and driving, no work appears to have been carried out on the variable of predictable versus unpredictable driving demands. And yet, the importance and relevance of studying the effects of irregular demands on the driver is self-evident in both military and civilian professional driving where such task demands may occur. Indeed, "irregularity" or "unpredictability" may more appropriately describe the demands in a military setting when operational in the field. Furthermore, it is worth asking how many accidents in civilian settings have occurred not only after prolonged driving but also at a time later than when the driver had expected to have stopped or completed his journey. The aim of this study therefore was to carry out a preliminary exploration of the relationship between task predictability and fatigue in a demanding HGV driving task.

METHOD

The task involved driving an instrumented and partly laden 7-ton rigid van-type Bedford in a convoy configuration behind a Renault 4 saloon car. Twelve volunteer professional army truck drivers were employed and each paid 88 pounds in addition to their normal wage. They were required to drive on various schedules for 4 consecutive days and to follow continuously the leading vehicle at such a distance as to prevent other vehicles from interposing, unless the interests of road safety dictated otherwise. Half of the subjects were fully informed about the work requirements for each day and half were kept totally uninformed.

Each day involved working a different schedule, randomly determined for each pair of subjects from a range of constrained possibilities to provide a total driving time of 6, 7, 8, and 9 hours with a starting time of 9.00, 10.00, 11.00, or 12.00 hrs on one each of the 4 days. Constraints were largely based on a review of current HGV work schedules operated by independent hauliers and employees of the state transport company in Ireland (see Fuller, 1978b) and were as follows. The maximum working day and driving span was to be 15 hours and the largest single block of continuous driving 5 hours. The number of blocks of driving per day was to be no more than 5 and breaks between blocks were to be of 30 minutes duration. Blocks of different durations of continuous driving for any subject comprised 7 blocks of 1 hour, 4 blocks of 2 hours, 2 blocks of 3 hours, and 1 block each of 4 and 5 hours, spread out over the 4 driving days. Within these constraints, random allocation of starting times, hours of driving, and number and duration of blocks of driving yielded the experimental schedules presented in Table 1. For each pair of subjects, one was given full information in advance of the 4 days and on each day separately about the task demands to be imposed on him (informed condition) whereas the other (usually the first of each pair) received only the simple instruction to be ready to drive from 09.00 hours on each day (uninformed condition). The six subjects in each condition were approximately matched for age with mean age informed group 28.3 years (sd = 5.2) and uninformed group 26.7 years (sd = 6.2). Routes driven differed for each pair of subjects but were invariably concentrated on rural trunk roads with a minimum of town driving.

Fatigue was measured from the perspective of three types of change, performance, experiential, and endocrine. The performance measure used was the driver's time headway and its variability, continuously monitored using a closed-circuit television system mounted in the instrumented heavy goods vehicle and described in detail in Fuller, McDonald, Holahan, and Bolger (1978) and with modifications reported in Fuller, Holahan, and Bolger (1980). Time headway is regarded as a particularly useful measure of performance because of the disproportionate representation of HGVs in rear-end collision accidents (Neilson, Kemp, and Wilkins, 1979; An Foras Forbartha, 1980); because average headway appears to be related to a measure of safe driving ability (Rockwell and Snider, 1965), and because it is possible to establish a straightforward criterion of safe following distance (Lehman and Fox, 1967).

Table 1

Experimental Driving Schedules

Subject	Day	Start	Blocks of driving	Finish	Hours driving	Working day
1/2	1	10.00	1 4 1 1 2	21.00	9	11.0
	2	11.00	5 1	17.30	6	6.5
	3	9.00	2 2 3	17.00	7	8.0
	4	12.00	3 2 1 1 1	22.00	8	10.0
3/4	1	11.00	2 1 4 2	21.30	9	10.5
	2	12.00	3 5	20.30	8	8.5
	3	10.00	1 1 2 1 2	19.00	7	9.0
	4	9.00	1 1 1 3	16.30	6	7.5
5/6	1	12.00	2 1 2 1 2	22.00	8	10.0
	2	11.00	5 1 1	19.00	7	8.0
	3	9.00	2 4 3	19.00	9	10.0
	4	10.00	3 1 1 1	17.30	6	7.5
7/8	1	11.00	1 1 1 3 3	22.00	9	11.0
	2	12.00	1 2 2 2	20.30	7	8.5
	3	10.00	1 5	16.30	6	6.5
	4	9.00	1 2 4 1	18.30	8	9.5
9/10	1	11.00	3 1 4	20.00	8	9.0
	2	9.00	5 2 1 1	19.30	9	10.5
	3	12.00	2 2 1 1	19.30	6	7.5
	4	10.00	1 3 2 1	18.30	7	8.5
11/12	1	9.00	5 1 2 1	19.30	9	10.5
	2	11.00	1 2 3	18.00	6	7.0
	3	10.00	2 2 3 1	19.30	8	9.5
	4	12.00	1 4 1 1	20.30	7	8.5

Experiential aspects of fatigue were monitored using a checklist concerning driving evaluation, motivation, and feelings of fatigue, routinely administered to the subject after each block of continuous driving. In addition, a semi-structured interview was held with each subject at the end of the experiment to explore the relationship between his expectations for the driving task and what was actually demanded.

Lastly, an assay for endocrine markers of physiological strain was carried out on drivers' blood samples (20 ml) taken immediately before and after each day's driving and on urine samples collected twice during the day. Equivalent samples were also taken on the day prior to the start of the experiment to provide tentative base-line values.

In summary, the independent variables manipulated in this study were task predictability, time-on-task, and days driving and the dependent variables were following performance (time headway and its variability), self-ratings of performance, motivation and fatigue, and a range of endocrine measures.

The procedure adopted was as follows. On the day preceding the start of his driving session (always a Monday) each subject was collected from his barracks and taken to a hospital endocrine unit. He was asked to complete a short form of the Eysenck Personality Inventory and given a brief "check-out" on the experimental vehicle. So that he would not be aware that his vehicle following performance would be under systematic observation, he was informed that the purpose of the study was to determine the relationship between schedules of driving and hormone level changes. It was explained that the experimental HGV was equipped with a television system designed to monitor general traffic conditions and that this equipment would be operated by an assistant riding in the van section.

At 10.30 hours a 20 ml blood sample was taken. S was then given two bottles to collect his urine over each half of the intervening period and requested to return with his bottles to the unit at 19.30 hours for a further blood sample. Subjects in the informed condition were given details of their work programme for the entire week whereas those in the uninformed group were asked simply to report back to the unit at 09.00 hours the following day. In order that subjects could make arrangements for transport home after work, it was also found necessary to inform them that they might be required up to 24.00 hours on any day.

On the remaining 4 days of the experiment the procedure for S was largely the same as for the initial day with the major additional requirement that he carry out the convoy driving task as described earlier and routinely complete the self-evaluative checklist. Again, drivers in the informed group were given full details regarding the onset and termination of each block of driving for each day, whereas uninformed group drivers were simply instructed to start and stop driving as and when appropriate with no foreknowledge whatsoever.

RESULTS

Leading Vehicle Variability. To determine the scale of the possible contribution of spontaneous variability in leading vehicle speed to variability in the follower's time headway, seven samples of leading vehicle speed of mean size 84 observations were taken on 5 different days at varying periods and when road conditions were such as not to require speed changes. Within each sample, leading vehicle speed was recorded at 5 s intervals. Mean sample variability (s.d.) was found to be 4.0 km/h, associated with an average speed of 55.7 km/h. Thus, assuming a constant speed (i.e., no response) on the part of the following driver, 95% of the entire sample of variations in leading vehicle speed would have affected the following driver's headway variability within the range ±0.15 s. In relation to the reliable periodic changes described later, this effect is unimportant and furthermore was not found to be systematically related to days, periods, or conditions.

Analysis of Time Headway and Time Headway Variability. Subjects' mean 30-min periodic time headway and variability were analysed in two ways. First, to examine the effects of conditions (informed v. uninformed) and periods, a series of two-factor factorial analyses of variance were carried out on the aggregate data for each length of driving (12, 14, 16, and 18 periods) and also separately on the results for steady-state following (SS), closing (C), closing-braking (CB), and steady-state following plus closing (SS+C), making 20 analyses each for time headway and time headway variability. For a description of the categories of following manoeuvre selected, see Fuller (1981). The general design was therefore a two-factor factorial anova with Information (2 levels) and Periods (12, 14, 16, or 18 levels) as main factors, repeated measures on the second factor, and $n = 6$. To explore the possibility of an effect due to days driving, a second set of analyses was carried out on the data for the first 12 periods of driving on each day, again treating the results for the various categories of following manoeuvre separately in addition to the aggregate data. The general design for this procedure was therefore a three-factor factorial anova with Information (2 levels), Days (4 levels), and Periods (12 levels) as main factors, repeated measures on the last two factors, and $n = 6$.

Information and Period Effects

The most salient feature of the results was a negative one in that no effect of Information was found whatsoever on either mean periodic time headway or its variability. A summary of significant effects is presented in Table 2. For the aggregate data, a long time headway was associated with the first half-hour period of driving and to a slight extent with the last period of the two longer schedules (see Figure 1). It should be noted that in Figures 1 through 5 the sd for schedules is shown where sd > 0.1. There was, of course, no sd for periods 17 and 18. Early long time headway was not characteristic of SS following, however, although it was generally the case for the other manoeuvres (SS+C, C, and CB--see Figures 2, 3, 4, and 5).

From inspection it may be seen that long time headway was associated with the end of the 18-period schedule for SS following (Figure 2), SS+C (Figure 3), and C (Figure 4) although the effect just failed to pass the significance criterion for SS and C. For the CB data, a terminal long time headway was more particularly associated with the end of the 16-period schedule (period mean = 3.8 s).

Table 2

Summary of Significant Effects for Time Headway and Headway Variability (Excl. Days)

Sample	Effect	Significant comparisons (units are seconds)
(a) Aggregate		
Time headway		
12	Period $\underline{F}(11,91)$ 4.22**	Period 1: 3.03 > all other: 1.86-2.22
14	Period $\underline{F}(13,115)$ 6.79**	Period 1: 3.50 > all other: 1.87-2.41
16	Period $\underline{F}(15,146)$ 5.52**	Period 1: 3.11 > all other: 1.88-2.36
18	Period $\underline{F}(17,144)$ 6.12**	Period 1: 4.14 > all other: 1.84-2.72
Time headway variability		
12	Period $\underline{F}(11,91)$ 2.31*	Period 1: 2.11 > all other except 7,10,12: 0.56-0.79
14	Period $\underline{F}(13,115)$ 3.47**	Period 1: 2.18 > all other except 2: 0.58-1.09
16	Period $\underline{F}(15,146)$ 4.59**	Period 1: 1.99 > all other except 16: 0.62-0.95
18	Period $\underline{F}(17,144)$ 3.40**	Period 1: 2.73 > all other except 2,18: 0.55-1.23
(b) Steady state + closing		
Time headway		
12	Period $\underline{F}(11,91)$ 2.12*	Period 1: 2.60 > all other except 2,6,11,12: 1.82-1.97
14	Period $\underline{F}(13,115)$ 4.61**	Period 1: 2.99 > all other: 1.84-2.34
16	Period $\underline{F}(15,146)$ 1.93*	Period 1: 2.33 > all other except 4,8-16: 1.74-1.86
18	Period $\underline{F}(17,144)$ 4.15**	Period 1: 2.99 > all other except 2,17,18: 1.78-2.29 Period 18: 2.66 > Periods 3-8: 1.78-1.95

Table 2 (Continued)

Sample	Effect	Significant comparisons (units are seconds)
Time headway variability		
18	Period $\underline{F}(17,144)$ 2.30**	Period 18: 1.59 > Periods 3-7,9-12,15,16: 0.48-0.66
		Period 2: 1.30 > Period 15: 0.48
(c) Closing		
Time headway		
12	Period $\underline{F}(11,87)$ 3.88**	Period 1: 3.14 > all other: 1.64-1.94
14	Period $\underline{F}(13,114)$ 5.33**	Period 1: 3.24 > all other except 2: 1.74-2.25
16	Period $\underline{F}(15,144)$ 2.55**	Period 1: 2.41 > Periods 2-7,14: 1.61-1.89
18	Period $\underline{F}(17,138)$ 6.34**	Period 1: 3.54 > all other: 1.64-2.56
		Period 2: 2.56 > Periods 4,5,6,8,9: 1.64-1.82
Time headway variability		
16	Period $\underline{F}(15,144)$ 2.12*	Period 16: 1.17 > all other except 1,9: 0.43-0.70
18	Period $\underline{F}(17,138)$ 2.94**	Period 2: 1.49 > all other except 1,13,17,18: 0.42-0.65
		Period 18: 1.20 > Period 4: 0.42
(d) Closing-braking		
Time headway		
12	Period $\underline{F}(11,71)$ 2.07*	Period 1: 5.41 > all other: 2.07-2.80
14	Period $\underline{F}(13,88)$ 1.96*	Period 1: 4.04 > Periods 5-7,10,12-13: 2.03-2.56
16	Period $\underline{F}(15,113)$ 3.35**	Period 1: 4.77 > all other except 2,3,16: 2.03-2.97
		Period 16: 3.82 > Period 8: 2.03
18	Period $\underline{F}(17,98)$ 1.81*	Period 1: 4.65 > Periods 6,9,10,16: 2.25-2.39
		Period 12: 5.25 > Periods 5-11,14-16: 2.25-2.89

Table 2 (Continued)

Sample	Effect	Significant comparisons (units are seconds)
Time headway variability 16	Period $\underline{F}(15,113)$ 2.35**	Period 1: 2.53 > Periods 4,5,7-9,11,12,15: 0.40-0.82

*$\underline{p} < 0.05$.

**$\underline{p} < 0.01$.

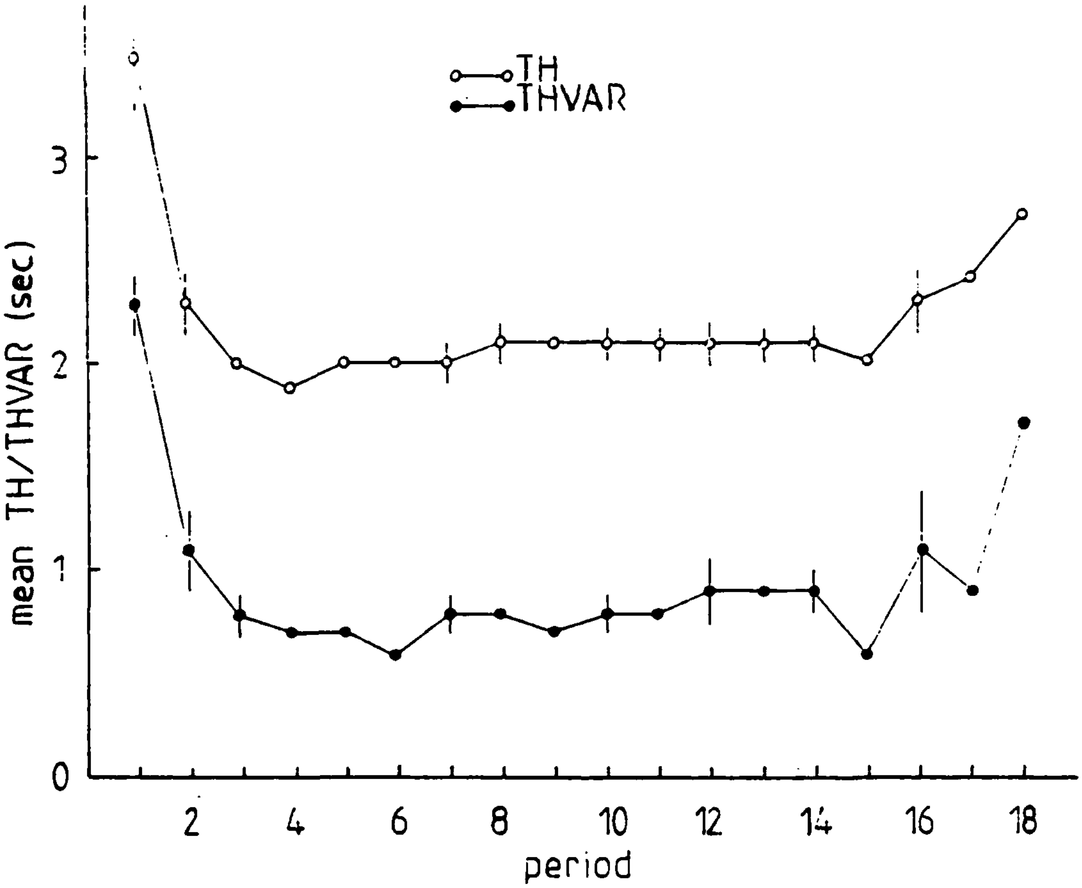


Figure 1. Time headway means and time headway variability for aggregate data (all schedules).

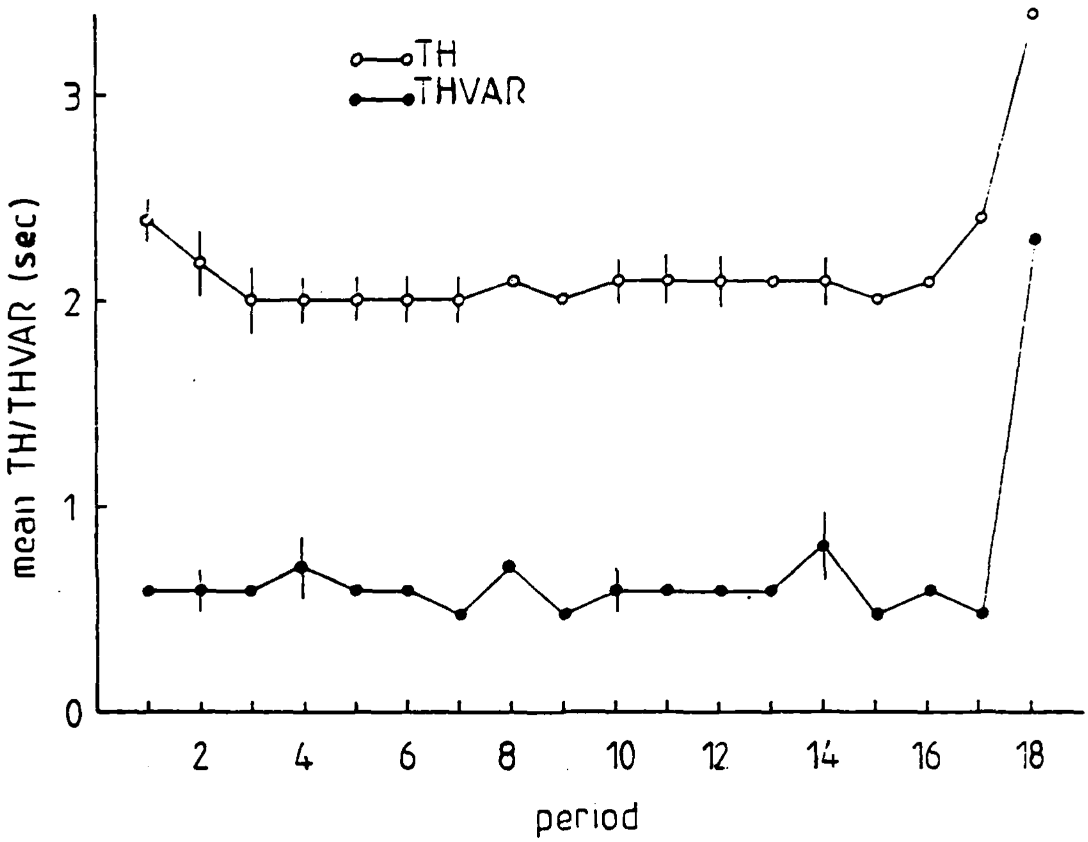
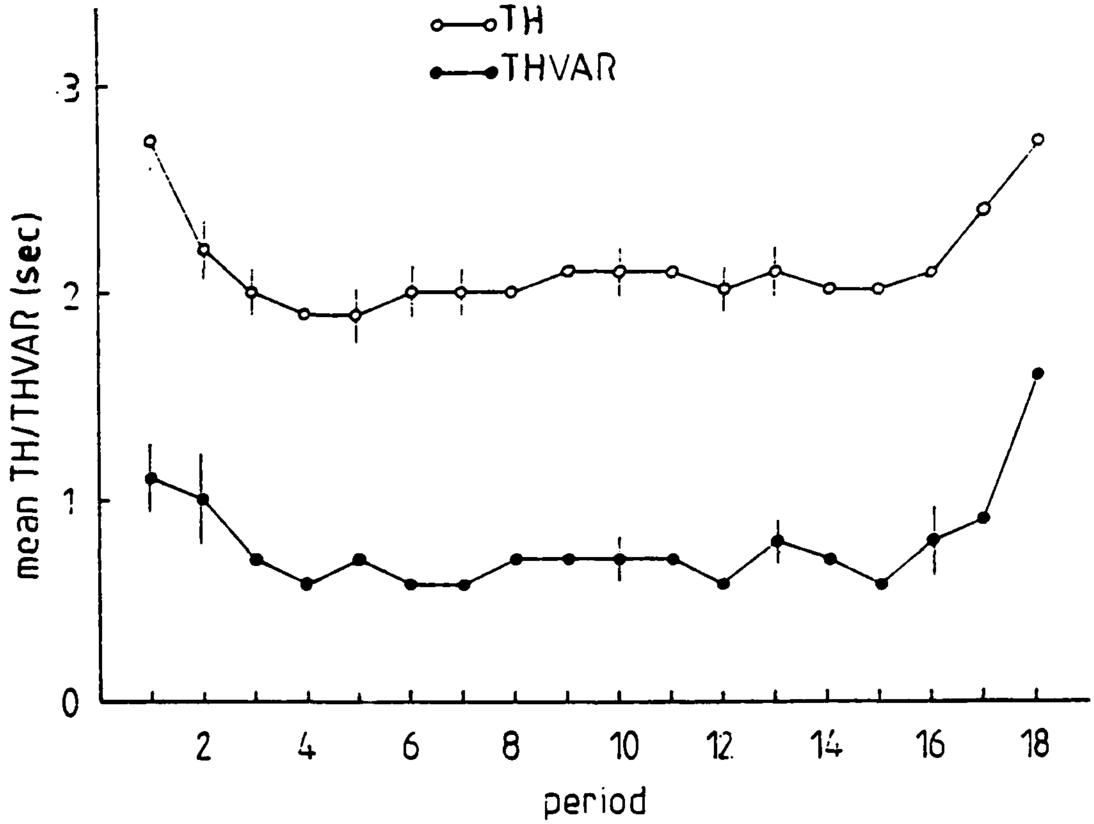


Figure 2. Time headway means and time headway variability for steady-state following data (all schedules).



<u>Figure 3</u>. Time headway means and time headway variability for steady-state + closing data (all schedules).

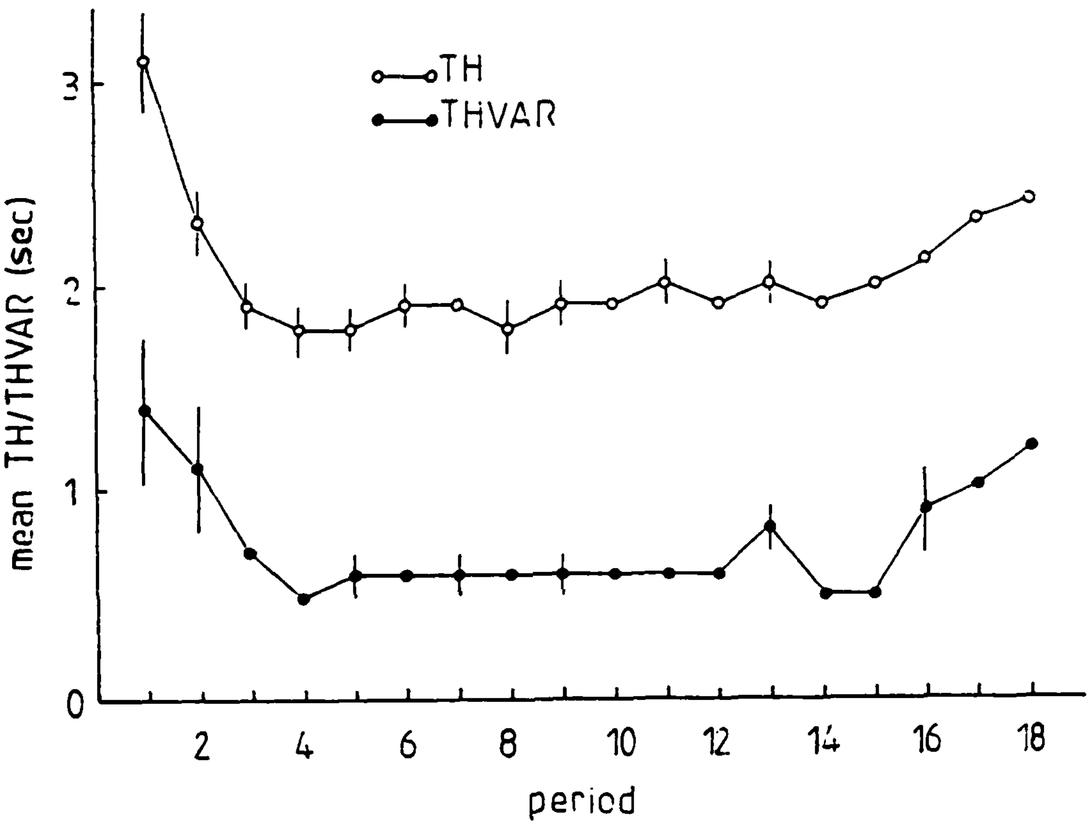


Figure 4. Time headway means and time headway variability for closing data (all schedules).

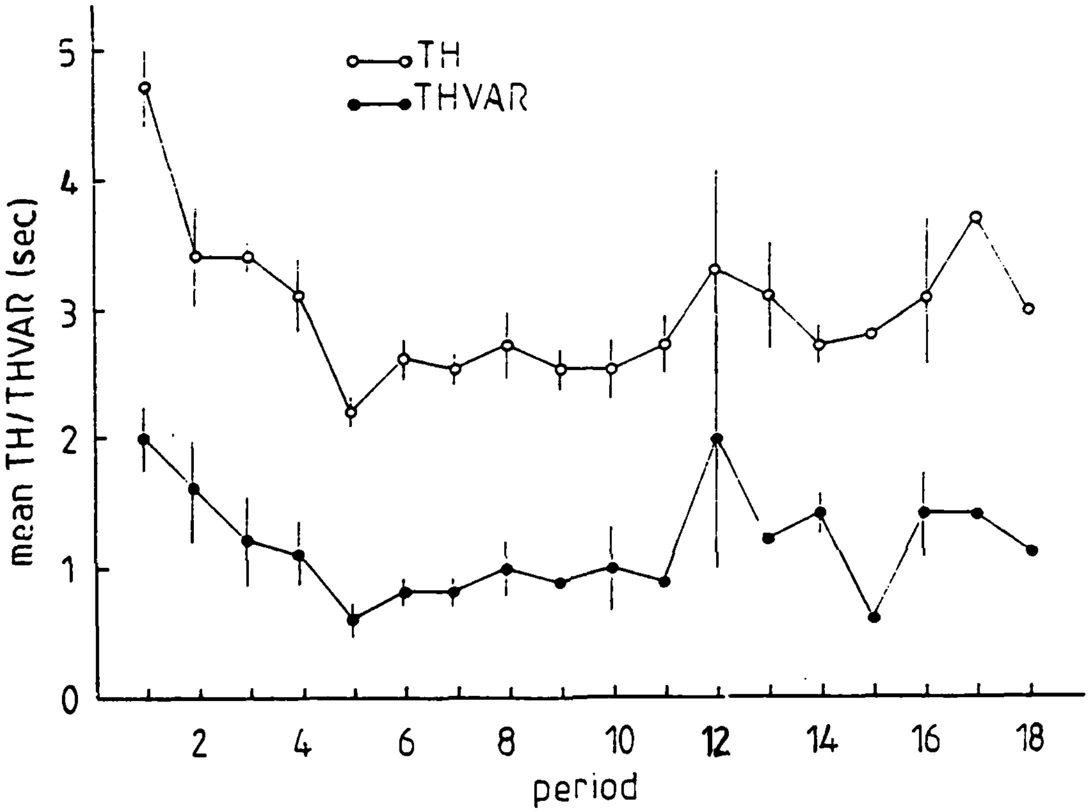


Figure 5. Time headway means and time headway variability for closing-braking data (all schedules).

The results for time headway variability follow a similar pattern to that for time headway. For the aggregate data, large variability was associated with the first half hour of driving and to a slight extent with the last half hour, particularly for the 16- and 18-period schedules (see Figure 1) which obtained terminal period means of 1.5 s and 1.7 s respectively. Again high variability in headway early on was not the case for SS following (Figure 2) but was typical of the other manoeuvres (Figures 3, 4, and 5).

Evidence for increased variability in the last half hour can be seen in the SS data (Figure 2) and was significant for SS+C on the 18-period schedule and for the closing manoeuvre on both the 16- and 18-period schedules (see Figures 3 and 4).

Days Effects

A summary of the significant effects for the Days analysis, which pooled the results for the first 12 periods of all schedules, is presented in Table 3. Although in the aggregate data there was no significant effect for Days, for the CB manoeuvre Day 1 had significantly longer time headway than the remaining days (Mean Day 1 = 3.6, Day 2 = 3.0, Day 3 = 2.7, Day 4 = 2.6). Furthermore, with regard to SS following, it was found that the typical period effect (time headway period 1 > remainder) was significant for Day 1 and Day 2 only and on Day 1 was not found for the drivers in the uninformed condition (see Figure 6).

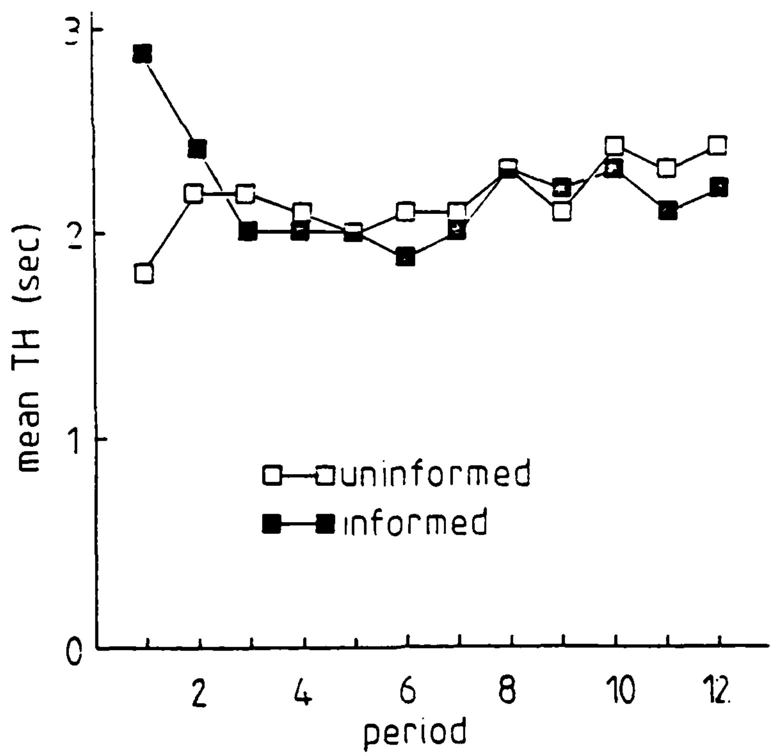


Figure 6. Time headway means for day one: uninformed and informed conditions for SS data.

Table 3

Summary of Significant Effects for Days Analysis

Sample	Effect	Significant comparisons (units are seconds)
(a) Aggregate		
Time headway	Period F(11,110) 61.40**	Period 1: 3.45 > all other: 1.92-2.31 Period 2: 2.31 > all other except 10,12
Time headway variability	Period F(11,110) 19.81**	Period 1: 2.25 > all other: 0.64-1.16 Period 2: 0.92 > Periods 4-6,9,11: 0.64-0.73
(b) Steady state		
Time headway	Day x Period F(33,254) 2.05**	Long time headway Period 1 found for Days 1 and 2 but not for Days 3 and 4
Time headway variability	Task x Period x Day F(33,254) 2.33**	Day 1 long time headway for Period 1 found for Informed condition only
(c) Steady state + closing		
Time headway	Period F(11,110) 7.68**	Period 1: 2.72 > all other: 2.01-2.17
Time headway variability	Period F(11,110) 7.42**	Period 1: 1.19 > all other except 5,8,10: 0.60-0.65
(d) Closing		
Time headway	Period F(11,110) 18.53**	Period 1: 3.04 > all other: 1.79-2.23 Period 2: 2.23 > Periods 4,5,7,8: 1.79-1.86
Time headway variability	Day F(3,30) 2.94* Period F(11,110) 24.47**	Day 2: 0.78 > Day 3: 0.58 Period 1: 1.30 > all other except 2: 0.50-0.66 Period 2: 1.09 > all other except 1

Table 3 (Continued)

Sample	Effect	Significant comparisons (units are seconds)
(e) Closing-braking		
Time headway	Day $F(3,30)$ 4.74**	Day 1: 3.58 > all other: 2.57-2.96
	Period $F(11,110)$ 6.42**	Period 1: 4.70 > all other: 2.24-3.38
Time headway variability	Day $F(3,30)$ 2.46*	Day 1: 1.73 > all other: 1.01-1.05
	Period $F(11,110)$ 2.08*	Period 1: 2.07 > Periods 5-9: 0.66-0.95
	Day x Period $F(33,186)$ 1.75*	Period effect significant for Days 1 and 2 only

*$p < 0.05$. **$p < 0.01$.

Analysis of headway variability revealed no effect for Days in the aggregate data but for the CB manoeuvre variability was found to be significantly greater on Day 1 (Mean Day 1 = 1.7, Day 2 = 1.1, Day 3 = 1.1, Day 4 = 1.0) and the typical effect for period 1 was significant for the first 2 days only.

Following Manoeuvres

Reviewing these results from the perspective of the different following manoeuvres, it may be seen that the overall results for steady-state following show a weak effect of the initial period of driving on time headway and on variability in comparison with the other manoeuvres of closing and closing-braking (compare Figure 2 with Figures 4 and 5). Results for the Days analysis revealed that this was because a period one effect was only apparent over the first 2 days of the experiment and that on Day 1 occurred only in the Informed condition. Why uninformed drivers should not exhibit the apparent need for a period of adjustment to the close following task is unclear, although it could be that in a state of uncertainty about task demands, drivers in this condition took steps to ensure that they did not lose the leading vehicle by driving close enough to prevent other vehicles from intervening.

With regard to the end of the driving day, some evidence was found for increased time headway and variability in steady-state following on the 18-period schedule. This result just failed to reach statistical significance because of the adjustment downward of the error term degrees of freedom to take account of missing data. Nevertheless the tendency for increased headway and variability did become much clearer and more reliable with the addition of the data for closing episodes.

A high value for time headway in closing episodes implies a cautious following strategy on the part of the driver and this was found to be typical of the first and second periods of driving. Early variability in closing was also found (see Days analysis) although this was not statistically reliable for each schedule length taken separately. Increased variability was also found for the last driving period of the day on the 16- and 18-period schedules.

Finally, in considering episodes of closing and simultaneous braking, it may be noted that a high value for time headway indicates positive deceleration of the following vehicle relative to the leading vehicle. Such episodes usually occur in response to braking by the front vehicle. The overall value for this manoeuvre was high (mean TH = 2.95 s) suggesting a particularly safe strategy on the part of drivers in this study. Again, an initial driving period effect was very evident in the time headway results although it was not so marked in those for headway variability and was reliable for the first 2 days only. Inspection of Figure 5 reveals an apparent upward trend in time headway and its variability after about the eleventh period but the effect for the terminal hour was found to be significant for only one comparison.

The general picture which emerges from these results is that the early part of the day is associated with a relatively long time headway and with relatively high headway variability. This is particularly the case for the earlier part of the experiment (Days 1 and 2) but not so evident in steady-state following for the uninformed group. Increased headway and variability are associated also with the end of the driving day, most especially on the longer schedules involving 8 or 9 hours of driving.

Distribution of Short and Long Headway Values

Further, to the analysis of mean periodic headway and its variability, an examination was carried out of the distribution over time and conditions of short (<1.0 s) and long (≥2.5 s) headway values. It was considered that this procedure might provide a more sensitive measure of possible effects of the independent variables. Two two-factor factorial Anovas were carried out on the proportions (expressed as percentages of headway values of either less than 1.0 s duration (overall % = 6) or equal to and greater than 2.5 s duration (overall % = 22) for each half-hour period of driving. The statistical design in each case was a 2 x 18 Anova with Information (2 levels) and Periods (18 levels) as main factors, repeated measures on the second factor, and $n = 6$. This procedure pools the data for Days and provides a matrix in which periods 1 through 12 are each based on 48 subject days, periods 13 through 14 on 36 subject days, periods 15 and 16 on 24 subject days, and periods 17 and 18 on 12 subject days.

No significant main effects or interactions were found for the short headway data but an isolated significant effect for Periods occurred in the analysis of long headway values ($F(17,170) = 5.64$, $p < 0.01$). Inspection of the relevant means revealed that the proportion of long headway values was significantly greater in the first period of driving (51%) compared with all others (17%-32%) and that the proportion in periods 17 and 18 (32%) was greater than in period 4 (17%) and 5 (19%). A graph of the mean percentage of both long and short headway values for each half-hour driving period is presented in Figure 7. Apart from the marked effect for period 1 and the relatively high proportions of long headways for periods 17 and 18, results which complement the findings for mean periodic time headway described earlier, what is apparent in these results is the suggestion of a fairly regular progressive increase in the proportion of long headways from period 4 onward (see Figure 7). The possible implications of this will be discussed later.

Experiential Aspects

Before Driving. With regard to the drivers' experience before driving on each day, the Informed group were slightly but not significantly more likely to state that they had slept "very well" (Informed--57% of nights, Uninformed--34%). Furthermore, they reported having had significantly more sleep (Informed--7.7 hr, $sd = 1.5$; Uninformed--6.8 hr, $sd = 0.9$; $t = 3.01$, $df = 29$, $p < .01$, 2-tailed test) and were less likely to describe themselves as drowsy or bored during the hour immediately before driving (see Table 4). Negative feelings expressed by Uninformed drivers were generally "slight" (75%) although on 4 days they admitted to being "very bored."

Expectations. At the beginning of the driving sessions none of the Uninformed group reported having had expectations about the nature of the driving schedules required whereas two of the Informed group thought incorrectly that they would repeat the same route each day and two also incorrectly expected that they would not receive advance information about starting and finishing times and destinations. Amongst this group one other subject had received a fairly full account from a colleague and another anticipated a kind of driving test or evaluation rather than participation as a subject in an experiment.

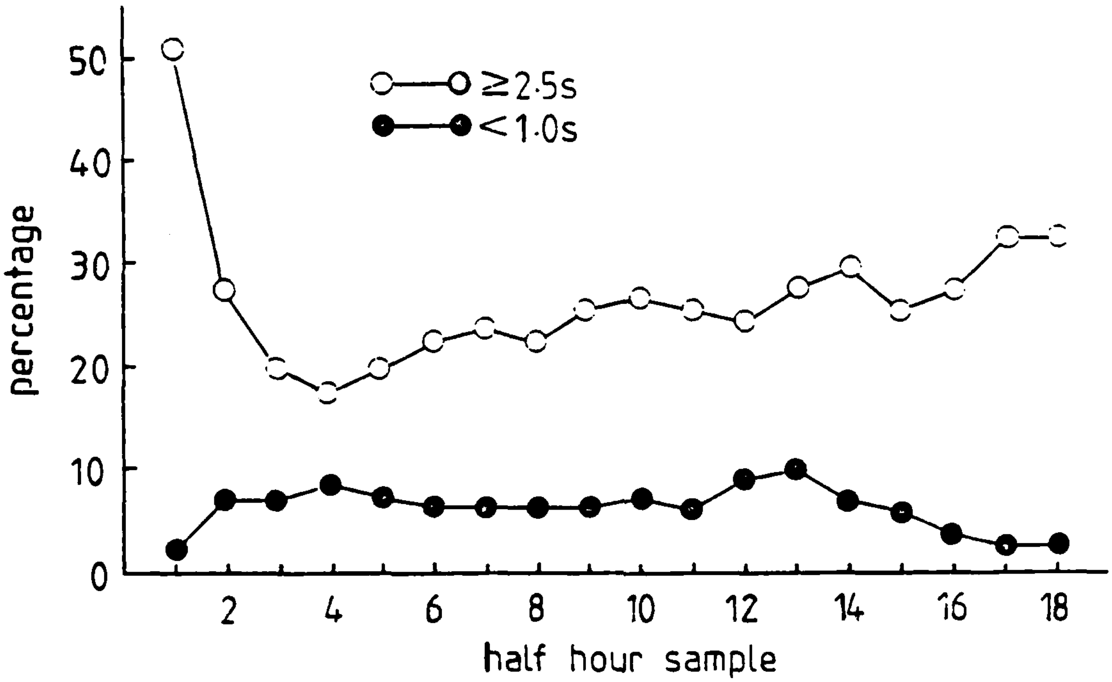


Figure 7. Percentage of time headway values of <1.0 s or ≥2.5s for each half-hour driving.

Table 4

Frequency of Feelings Expressed for Hour Before Driving

	Drowsiness	Boredom	Irritation	Exhaustion	Physical discomfort
Uninformed	10	11	0	5	1
Informed	1	2	6	2	1

During the week, three of the Uninformed group reported developing some kind of expectation for the task but only in a very generalised form. Thus one simply expected the going to be "heavy and monotonous" and two expected that the lack of information about schedule onset and duration would continue. As one driver put it, he came to expect burnt dinners when he got home!

Only two of the Uninformed group admitted to having to do more than expected during the week. For one driver it was late finishing on the first day (22.00 hrs) and for the other it was continuing on driving on the third day after once returning to the city (home base, as it were). This result implies that the experimental manipulation of information had far less impact than was anticipated. For most of the time, drivers in the uninformed condition did not have to do more than they appear to have been prepared for. This situation is aptly reflected in a comment by a member of the Informed group that when he volunteered he was "ready to drive until 22.00 hrs each night." Perhaps not surprisingly, all of the Informed group and two of the Uninformed group reported that on some days they had to do less than they had anticipated prior to participating in the study or in the case of the Uninformed group, once it was underway. Exposure to a relatively heavy schedule in the latter group seems to have had the effect of resetting the upper limit of expected demand such that any schedule falling short of that limit turned out to be a kind of bonus. At the end of the week no subject in either group complained about the work required and four in each reported having enjoyed it.

Driving Performance. For each block of driving drivers rated six aspects of their performance on a 5-point scale ranging from "very" to "not at all." The aspects were driving ability, observation, control, decision making, courtesy to other road users, and riskiness. To analyse the effects of the Information variable on ratings of these aspects the data for each day were treated as independent samples and scores for matched pairs of subjects were compared using the Wilcoxon Matched-Pairs Signed-Ranks test. No significant effects were found for any of the six dimensions of driving performance although there was a suggestion that Informed drivers rated themselves as more courteous (mean rating per block Informed group: 1.2; Uninformed group: 1.5; where a rating of 1 = very courteous, 2 = quite courteous) and better at decision making (mean rating per block Informed group: 1.3; Uninformed group: 1.6; where rating of 1 = very good decision making and 2 = quite good decision making). Examination of the data over days and over blocks of driving revealed no systematic trends and no interactions with the Information variable.

Feelings of Fatigue. No effect of Information was found on ratings of drowsiness, exhaustion, or of awareness of what the driver was doing and not one hallucination was reported under either condition. Nevertheless, a significant effect was found for ratings of daydreaming ($T = 0$, $N = 18$, $p < 0.01$, 1-tail) with the Informed group being about six times more likely to daydream than the Uninformed group (Uninformed group daydreamed on 13% of driving periods; Informed group on 76%). Inspection of the data over days revealed no pattern nor any interaction with Information conditions.

The effects of time driving within days was analysed by comparing differences in ratings between the first and last period of driving on each day. Although little change over time was observed and no significant effects, a suggestion of a small increase in both drowsiness and exhaustion over time, independent of Information condition, was observed. Drowsiness increased on 25% of days and exhaustion on 17%. On only 2 days (4%) were changes noted in the opposite direction. Similarly, the likelihood of daydreaming under both Information conditions was found to be more likely to increase rather than decrease over time. Indeed although the probability of no change over time was by far and away the greatest ($p = 0.78$), drivers were 10 times more likely to daydream more in the last period of driving ($p = 0.20$) than in the first ($p = 0.02$).

Motivation. Drivers' motivation under each condition was evaluated by asking them at the end of each day how prepared they were to drive on for a further period of time and by asking them to rate their feelings on dimensions of boredom, irritation, comfort, and awareness of time passing.

With regard to preparedness to drive on for longer, it may be seen from Table 5 that for about 73% of days drivers felt they could have driven on for longer (about 2.4 hours on average); for about 4% of days they felt like stopping earlier (1.0 hour on average), and for about 23% of days they felt the time about right. As may be seen from the table, however, there was no noticeable effect of conditions on this distribution of preferences and analysis by Days revealed no other effect or interactions.

Table 5

	Uninformed	Informed
Felt like driving on for longer	71	74
Felt like stopping earlier	5	4
Felt period about right	24	22

Lastly, with regard to this experiential analysis, no significant effects were found for ratings of Boredom, Irritation, Experience of time, or Physical comfort, although there was a suggestion that for the Informed group on the first 2 days time seemed to pass more slowly, they were more likely to become more aware of the passage of time whilst driving, and they were also more likely to experience a slight decrease in comfort.

Endocrine Variables

Serum levels of Cortisol and Testosterone were analysed for effects of driving, Information condition, Days, and Pre-post samples. There were no significant effects or interactions. Urine levels of adrenalin and noradrenalin were similarly analysed except that the sampling contrast was for early versus late in the driving day rather than Pre-post driving but again no significant effects or interactions were found.

It should perhaps be noted that, because of the design of this study, there was large temporal variation in blood and urine sampling for both first and second samples, which must have contributed to the large within-sample variation in values observed and made it more difficult to establish reliable changes over time. Nevertheless, the absence of evidence of biological strain was characteristic of both Information conditions.

DISCUSSION AND CONCLUSIONS

Withholding of information for 4 consecutive days about focal driving task requirements such as when driving would start, the duration of driving periods, and the end of the working day had no effect on drivers' performance, no effect on endocrine responses, and little effect on the driver's experience of the task. In the light of these findings it would be tempting to conclude that task predictability was unrelated to the onset or expression of fatigue in a continuous convoy driving task such as that investigated here. However, postexperimental interviews with the drivers revealed that such a conclusion would be premature. Rather than generally expressing distress at their deprivation of information or at having to satisfy driving requirements for which they were not prepared, only two uninformed drivers admitted to having to do more than expected and two even reported that on some days they had to do less. On only 5% of days did this group state that they would like to have stopped driving earlier and four members concluded that they had enjoyed working under the experimental conditions imposed. Clearly, despite the deliberate withholding of information about driving requirements, subjects formulated their own expectations and these appear to have generally been in excess of the demands actually placed on them.

One possible way of avoiding this demonstrably effective way of adjusting to the experimental manipulation would be to present drivers with explicit information about when driving would end and once that point was reached to then require further driving. Such a manipulation would more closely approximate the conditions which occurred inadvertently in an earlier experiment when a marked reaction from the driver was provoked. However, such a test of the hypothesis would involve considerable deception and would clearly be unethical. Perhaps the most appropriate if logistically difficult way of pursuing it at this time would be to isolate accidents attributed to factors such as drowsiness and fatigue and then determine the extent to which involved drivers were driving beyond the point at which they had originally intended to stop.

In spite of the failure of the Uninformed condition to operate as intended and the corresponding successful adaptation by drivers to their lack of information, a general pattern of temporal trends in the results was observed which replicates the findings of an earlier study in which drivers on a late shift were required to drive for 11 hours per day on each of 4 consecutive days in a continuous two-vehicle convoy (Fuller, 1981). In both studies long headway intervals are associated with the end of driving. Indeed in the present study the proportion of long headways increases fairly regularly from the fourth period onward. Secondly, both studies show slight but consistent increases in drowsiness, exhaustion, and daydreaming over time and lastly both studies reveal these changes in the absence of any real evidence of an endocrine stress response.

If drivers perceive that their capability is progressively deteriorating during the driving task, then perhaps they increase headway (for any given speed) as a form of compensation, avoiding an increase in riskiness by reducing the effective demands on themselves. Such an adjustment would be consistent with the absence of any endocrine stress response, the general preparedness of drivers to continue on driving after the end of the required time, and the majority expression of having enjoyed the driving overall.

Furthermore, this interpretation is also consistent with the observation by Forbes (1959) that hazards in tunnels tend to increase time headway and the finding by Fuller (1978a) that relatively short headways in vehicle following occur when there is a very low probability of sudden deceleration in the leading vehicle.

Safe driving performance clearly requires adjustive behaviour (McGlade, 1970). The results of this study indicate that appropriate adjustments may occur not only in the management of the gap between a driver and the vehicle in front but also in the driver's expectations about task parameters. Where there is general uncertainty regarding such parameters, he may pace himself effectively by anticipating a work load in excess of what he actually ends up having to do.

ACKNOWLEDGMENTS

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APPENDIX H

THE CAR AND DRIVING: A BEHAVIOURAL CONCEPTUALISATION

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MODELS OF DRIVER MOTIVATION

For most of the time on the road it is the driver's own actions which determine the difficulty of his task. Driving is essentially a self-paced activity. Because of this it may be argued that the driver's motivation is at least as important, if not more so, than limitations of his perceptual-motor capabilities in contributing to the safety of his performance (Näätänen & Summala, 1976).

Two models of driver behaviour, which emphasise the motivational variable and indeed differ principally on it, have been presented in recent years. They are Wilde's Theory of Risk Homeostasis (e.g., Wilde, 1981) and the Zero-Risk Model of Driver Behaviour proposed by Näätänen and Summala (1974, 1976).

The motivational dimension of Wilde's theory is conceptually closely related to earlier suggestions made by Taylor (1964) and Cownie and Calderwood (1966), who respectively posited that drivers drive so as to maintain a level of anxiety they wish to experience and that accidents are self-regulating in a closed loop system. Wilde's theory proposes that at any moment a driver makes adjustments so that his perceived level of subjective risk of accident equals some internalised target level of risk. Since this level of risk is generally greater than zero, adjustment actions carried out by drivers necessarily carry a certain objective risk of accident. Thus if over a period of time there is no reliable decrease in drivers' target risk levels, some related accident frequency-severity outcome will be maintained. As Wilde (1976) succinctly puts it: "Accident tolls and caution relate to one another in a compensatory function."

According to Wilde, a number of factors raise target level of risk, such as rewards for fast driving, but only by reducing this target level can a permanent decrease in the accident frequency-severity outcome be obtained. He concludes therefore that road safety measures should be directed at stimulating the desire to avoid accidents per se and speculates that much of human behaviour may be inherently risky by preference.

Although Wilde (1981) cites evidence which may be interpreted to support his concept of a target level of risk maintained by drivers, a considerable amount of evidence refutes the hypothesis. McKenna (1982), for example, points out that highway modification and seat belt usage are two areas of intervention in which, at least over the time periods studied, reductions in the accident frequency-severity outcome have been well-documented.

It is worth noting that Wilde's current theoretical position (e.g., Wilde, 1981) appears to have shifted slightly from an earlier one (e.g., Wilde, 1976) in which he proposed that drivers were motivated to avoid exceeding a tolerated level of subjective risk or danger, rather than aimed at maintaining some target level. With one exception this earlier position clearly avoids the implication that road safety measures directed at anything other than the desire to avoid accidents will be doomed to failure in the long run. What would also be critical in determining accident outcome would be the extent to which drivers were motivated or forced to operate at their tolerated risk ceilings.

Both Wilde's earlier and current positions are in marked contrast to that of Näätänen and Summala, who hold the road users' preferred level of risk (of accident or arrest) to be zero at all times. In the driver's decision making this zero-risk preference counteracts opposing pressures which they call "extra motives," pressures such as the desire to drive at an unsafe high speed. Accidents generally occur because the driver's subjective risk threshold is too high, that is when subjectively the risk of a particular action is zero but objectively it has some greater value.

Factors which raise the driver's threshold for the experience of subjective risk are perceptual errors, "extra motives," or the extinction of feelings of risk brought about by forced confrontations with traffic which turn out to be nonaversive. Thus, according to Näätänen and Summala, accident prevention measures should be aimed at lowering the threshold of subjective risk (i.e., reducing the discrepancy between subjective and objective risk), preventing drivers from ever reaching their risk threshold, and finally lowering objective risk at each point on the driver's subjective risk continuum.

One implication of this model, which has questionable face validity at least, is that drivers never tolerate the experience of risk in order to benefit from some gain such as getting somewhere within a particular time period. In such circumstances Näätänen and Summala would presumably argue that the driver's threshold for the experience of risk is raised so that subjectively risk level remains at zero. The validity of their concept of an inevitable dissociation between subjective and objective risk has recently also been questioned by Brown (1980).

Another difficulty with the model is the role in decision making played by subjective risk, a difficulty adumbrated by McKenna (1982). Näätänen and Summala (1976) state that:

> In general, the present model suggests that the subjective-risk reactions of road users constitute an important determinant of decision making and behaviour on the road, counteracting the behavioral tendencies associated with the existing, generally excitatory kinds of motives (pp. 189-190).

On the other hand, they also assert in several places in their text that "... the majority of road users, most of the time, feel no subjective risk at all" (p. 19). If this is indeed the case, the questions arise as to how subjective-risk reactions can be an important determinant of driver behaviour and why the subjective risk of an accident is zero most of the time.

Answers to these questions are in fact provided by Näätänen and Summala but are not presented in such a way as to form a coherent part of their conceptualisation. From various parts of their text one may rescue the following general argument. In essence, the experience of subjective risk is aversive (p. 201) and so drivers are motivated to escape from situations which elicit the experience (pp. 190, 220, 239) or avoid those situations (pp. 152-153). In this way subjective-risk reactions may be seen as an important determinant of driver behaviour and it also follows that if much of driving consists of learned avoidance responses, drivers will rarely experience any subjective risk of accident at all.

This exposition of a fundamental dimension of the Näätänen and Summala model constitutes the beginnings of a behavioural conceptualisation of driver motivation. Such a conceptualisation is developed further below through a behavioural analysis of the driving task which results in the formulation of a threat-avoidance model of driver behaviour. Parsons (1979) has voiced the potential value of such an approach to driving and it is suggested that this preliminary step will provide a more explicit basis for the understanding of driver motivation as well as hopefully overcome the more serious difficulties associated with earlier models described above.

A BEHAVIOURAL ANALYSIS OF DRIVING

Compared with most other things we do, driving has a high potential for aversive consequences. To achieve his travel objective, a driver cannot simply select a suitable heading and speed and then sit back and keep watch. Once in motion, he must continuously and actively make adjustments not only to attain his desired travel objective (i.e., a particular destination, usually within a particular time period), but also to avoid aversive stimuli or situations such as driving off the roadway, losing control of his vehicle, or colliding with another road user (McGlade, 1970; Parsons, 1976, 1979; Risk, 1981). A simple representation of a driver's options when confronted with such potential aversive stimuli or situations is presented in Figure 1.

Given a discriminative stimulus or warning signal (Figure 1, box a) for some impending potential aversive stimulus (box b), the driver may either make an anticipatory avoidance response (box c), which if successful cancels out the potential aversive stimulus (box d), or make no avoidance response (box e). This latter includes not only not responding but also making responses which compete with an avoidance response (see Parsons, 1979). Because in the normal road environment the correlation between discriminative stimuli and potential aversive stimuli is frequently less than unity, a non-avoidance or competing response may be followed either by the potential aversive stimulus (box b) or by no such stimulus (box d). If the former obtains, then the driver must make a delayed avoidance response from it (box f) or experience an accident (box g). In the sense used here, anticipatory avoidance responses occur prior to feedback to the driver about whether the response is necessary, whereas delayed avoidance responses only occur when they are perceived to be necessary. Thus, anticipatory avoidance responses, unlike delayed avoidance responses, may be made without any certainty that they are required for safety.

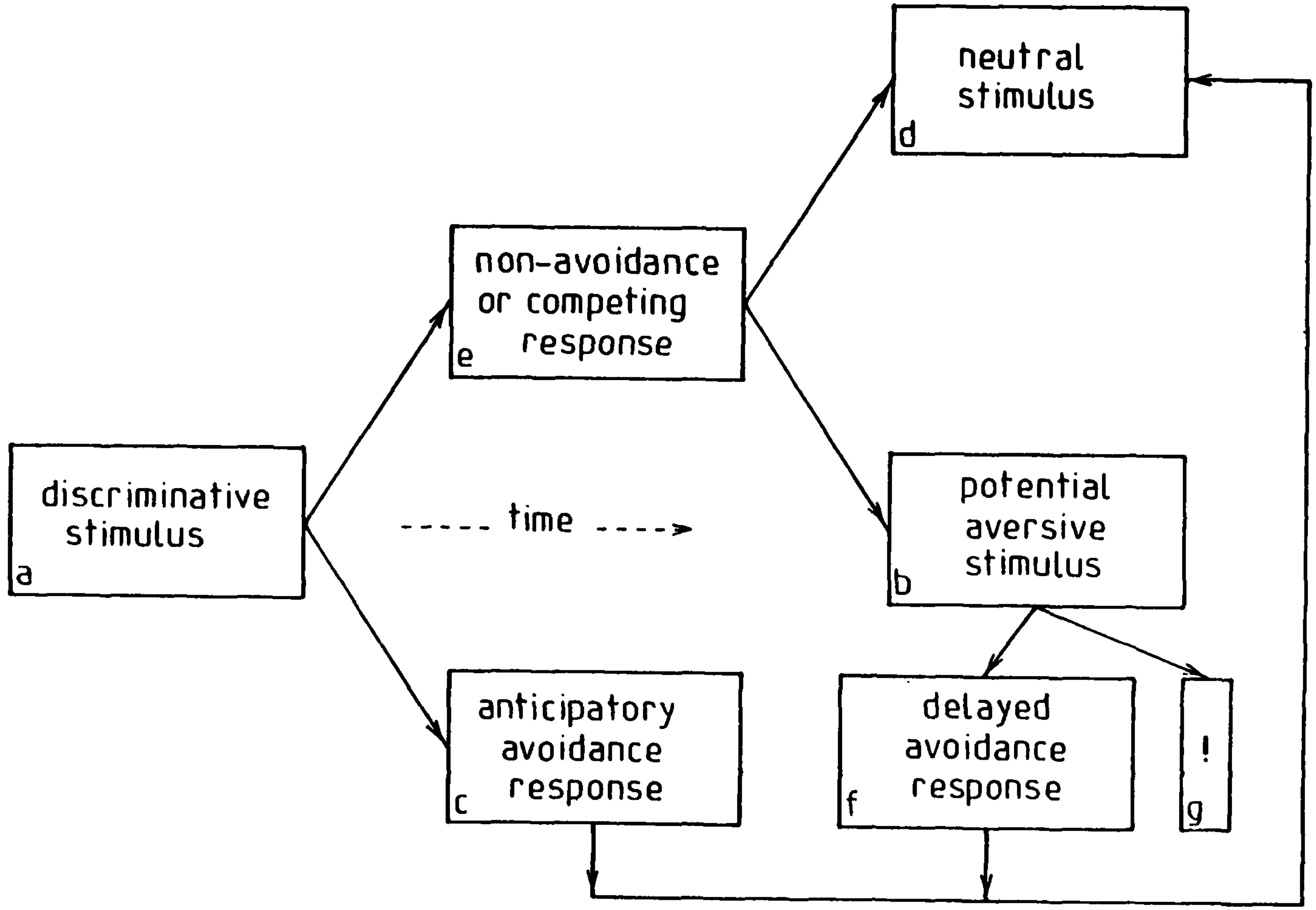

Figure 1. Simple avoidance analysis.

Applying this conceptualisation to a particular driving situation, imagine a driver on a very narrow road approaching a blind corner. A potential aversive stimulus (box b) might be an unseen vehicle coming from the opposite direction. The discriminative stimulus for such an event (box a) would be the blind corner itself, together with the driver's speed and perhaps also his performance capability. In response to this "integrated" discriminative stimulus, the driver may make an anticipatory avoidance response (box c), such as slowing down and perhaps concentrating his visual fixations on the bend ahead. This procedure should make the actual occurrence of an oncoming vehicle nonaversive (box d) because the driver will be able to pull over or stop in good time.

Alternatively, in response to the discriminative stimulus, the driver may make no anticipatory avoidance response at all (box e) and continue at his original speed. This again may be quite safe if there turns out to be no oncoming vehicle (box d). But if a vehicle appears (box b), the driver must make a delayed avoidance response (box f), such as relatively rapid braking and steering adjustment, or collide with it (box g). In general, except where avoidance responses are inappropriate to the situations in which they are executed, it is assumed that the more they are delayed the greater is the objective risk of accident. This occurs because the more imminent an aversive stimulus, the shorter is the available time to respond and the smaller is the range of avoidance options.

DISCRIMINATIVE AND POTENTIAL AVERSIVE STIMULI

As may be inferred from the schema represented in Figure 1, for an anticipatory avoidance response to occur an association needs to be established between a potential aversive stimulus and some precursor of that stimulus. This is called a discriminative stimulus in box a of Figure 1 but may also be called a conditioned stimulus (see Schwartz, 1978). Discriminative stimuli may be external to the driver such as hazard warning signs; deteriorating weather conditions; and, perhaps most frequently, particular features or configurations of the traffic environment. However, they may also be internal to the driver and include variables such as perceived impairment in capability.

Many aversive stimuli associated with the road environment are rarely experienced by the road user. Their importance lies in their potential as a consequence for certain acts. Amongst such stimuli might be included loss of control of the vehicle, physical injury, material damage, premature cessation of journey, financial loss, unpleasant interactions with police and with other road users, loss of license, and perhaps also loss of self-esteem. Other situations which might also be experienced as aversive and which are probably much more common are a loss of self-pacing in the driving task and a state of high arousal. A loss of self-pacing might occur, for instance, in a situation in which a driver had less time available than he would prefer in order to make decisions and control responses and more generally in which the level of performance demanded exceeded the level he was prepared or indeed able to make available.

An upward shift of arousal might occur as a response in anticipation of one or more of the forms of aversive stimulus indicated above and within limits may be considered adaptive in facilitating safe adjustment to a threatening situation. Nevertheless, increased arousal is frequently associated with feelings of negative affect, experienced as fear, tension, anxiety, panic, stress, or risk, and above some threshold may be considered aversive. The intensity of such feelings presumably escalates as other forms of aversive stimulus such as collision become more imminent.

MOTIVATION FOR ANTICIPATORY AVOIDANCE, COMPETING, AND DELAYED AVOIDANCE RESPONSES

As indicated earlier, anticipatory avoidance responses include not just vehicle control operations but also "information input" responses, such as scanning a particular part of the road environment, and also may be included "readiness" responses such as placing a foot on the brake pedal without actually depressing it. As a result of previous experience, such responses may become conditioned to particular discriminative or conditioned stimuli and may be conceptualised as conditioned avoidance responses (CARs). In competition with alternative responses, such responses are reinforced to the extent that they are more frequently followed by rewarding consequences and less frequently followed by aversive or punishing consequences (assuming different rewarding and punishing consequences have equivalent values). Thus, if a driver has a choice between two responses x and y which differ only in that response x is more likely to be followed by an aversive consequence, the driver will tend to select or make the alternative response y.

One reason why drivers do not inevitably do this is of course that aversive consequences are not a necessary conclusion to failing to make an anticipatory avoidance response (see path e-d, Figure 1). The potential aversive stimulus may simply not be realised. It seems likely that, ceteris paribus, the probability of a driver making an anticipatory avoidance response is related in some systematic way to his subjective probability of a potential aversive stimulus arising. Thus, where this probability is low, he is less likely to make an anticipatory avoidance response than where it is high. In this connection Wilde (1976) has suggested that drivers tend to underestimate low probabilities of potential aversive stimuli and overestimate high probabilities. This conclusion is based on the results of a study by Roer (1968) in which it was found that drivers make proportionately more accident avoidance responses when approaching high-volume intersections (relatively high probability of aversive stimulus arising) compared with low-volume intersections (relatively low probability of aversive stimulus arising).

Anticipatory avoidance responses are reinforced by information or feedback that the response was necessary. For many traffic situations, such as high-volume intersections, avoidance responses are presumably maintained on a fairly high variable ratio schedule. Nevertheless, extinction of the response could occur with an accumulation of feedback that anticipatory avoidance was unnecessary (see, for example, Hakkinen, 1965). This situation is demonstrated in a study of drivers' speeds approaching bends on narrow (4.1-4.5m) roads with very infrequent traffic, undertaken by the Swedish Traffic Safety Council in 1960 and discussed by Svenson (1977). Results showed that drivers unfamiliar with the roads generally adjusted their speeds so that they could stop if they met an oncoming vehicle. On the other hand, drivers who were familiar with the roads, and had presumably learned that the probability of meeting a car was very low, were much more likely to adopt speeds which would have made it impossible to avoid collision with an oncoming vehicle. One problem for safety motivation is therefore that of maintaining anticipatory avoidance responses in the face of feedback that such responses are rarely necessary.

A second reason why an anticipatory avoidance response is not made may be that the response itself is punished. Perhaps the most frequent avoidance response made by drivers is that of reducing speed. However, reductions of speed may have aversive consequences for the driver, such as making him late for an important appointment or missing a connection with some form of public transport.

A special case where selected speed may compete with anticipatory avoidance responses occurs as a result of experiencing unexpected delays in traffic. Where a driver is free to select his own speed he will generally choose one which, taking into account expected delays, will enable him to reach his destination within a desired time period. Unforeseen delays therefore require him to cover subsequent roadway at a faster speed than originally planned, and this faster speed may constitute a competing response. A similar phenomenon may be seen in gap acceptance when joining a traffic stream. Ebbeson and Hassey (1973) found that drivers accepted shorter gaps the longer they had to wait.

A further situation where an anticipatory avoidance response is not made might occur where a competing or nonavoidance response is intrinsically highly rewarding. A competing response of high speed, for instance, may itself be rewarding because it increases arousal to a more satisfactory level or simply because it is experienced as exhilarating. In addition, drivers may also be motivated to maintain a high speed in order to project the image of a fast driver, which in turn may bring rewarding consequences.

In all of these instances where the driver's elected speed is in competition with an anticipatory avoidance response, the competing response is in a sense further reinforced by the relative certainty with which it will result in its goal (such as arriving on time for something), whereas the requirement for avoidance may not be at all certain and furthermore may be delayed without necessarily incurring aversive consequences even if a potential aversive stimulus should arise. Competing responses which are incompatible with (i.e., prevent) <u>delayed</u> avoidance responses, however, are apt to be punished in the event of a potential aversive stimulus being realised. Such responses are likely, therefore, to have a very low probability in the experienced driver's repertoire. This conceptualisation of a limiting condition for competing responses corresponds to a motion discussed by Brown (1980) that driving decisions depend heavily on the subjective probability of what he calls "recovery from error." In general, it may be stated that, other things being equal, the more competing responses are rewarded and the less they are punished the more probable will they be as an alternative to an anticipatory avoidance response.

An important case of competing response worth noting occurs where a delayed avoidance response (box f in Figure 1) is itself more rewarding to the driver than an anticipatory avoidance response. This situation might occur because the delayed avoidance response

(1) is associated with a rewarding arousal increase;

(2) generally demands more rapid decision making and response execution which may be intrinsically more rewarding (e.g., as the exercise of a "higher" level of competence);

(3) is construed as requiring characteristics of courage or "nerve" which the driver wishes to display. This phenomenon can readily be seen in children's games of "chicken" where status is gained from facing up to threats for as long as possible rather than avoiding them.

In addition to these possible rewards for delayed avoidance, such responses could be strongly negatively reinforced because of their proximity to a potential aversive stimulus and thus in one sense be easier to learn.

In summary then, what is being proposed here is that the particular patterns of responses followed by a driver as represented by the schema described in Figure 1 depends on the degree of association (or dissociation) between a discriminative stimulus and a potential aversive stimulus and the rewards and punishments for anticipatory avoidance, competing, and delayed avoidance responses. Clearly the driver's previous experience is paramount in determining the nature and values of each of these variables and so, not surprisingly, the analysis has implications for a conceptualisation of the task of the learner driver.

IMPLICATIONS FOR THE LEARNER DRIVER

Other things being equal, learner drivers are more likely than experienced drivers to make delayed avoidance rather than anticipatory avoidance responses. This occurs simply because it requires experience of the road environment to learn the precursors of hazards, to develop the association between discriminative stimuli and potential aversive stimuli. Delayed avoidance responses, when brought forward, in time become anticipatory avoidance responses (even though the form of the response may change). Much of what is involved in learning to drive safely may be characterised by this shift.

A second point is that the learning of the consequences of one's actions in particular stimulus situations is clearly fundamental to the learning of safe driving. This includes the experience of both positive and negative consequences, although the latter may be somewhat attenuated by the "forgiving" nature of many road systems, particularly where the error of one driver is corrected or compensated for by the actions of another or others.

Nevertheless, inexperienced drivers are disproportionately overrepresented in accident statistics and methods to facilitate their learning the negative consequences of inappropriate driving responses without anyone suffering these directly would clearly be an advantage. Some learning may perhaps be assimilated as a set of driving rules (e.g., "never overtake on a blind corner") and some may come about vicariously through exposure to the actions of others and stimuli such as filmed high-risk driving and its consequences. However, it seems likely that most learning will occur through direct experience of contingencies, particularly of near misses, narrow escapes, and, unfortunately, accidents, when unsafe responses have been made. It may be noted in passing that the emphasis here on the relationship between accident involvement and inadequate learning experience in the young driver is in marked contrast to the view of Näätänen and Summala, who suggest that young drivers' accidents are due rather to the relative strength of "extra motives" in that group (op. cit., pp. 91-99).

A further implication of this analysis for learning safe driving relates to individual differences in speed of conditioning. The evidence that conditioning may be slower in extraverts compared with introverts (Eysenck, 1957) may in part explain their over-representation in traffic accidents, particularly the over-representation of the young extraverted driver to which attention has been drawn by Smith and Kirkham (1981). If it is assumed that after some point additional increments of experience yield diminishing returns in learning about contingencies, then it is perhaps not surprising that the young extravert should eventually approximate his more introverted peers in performance safety.

A THREAT-AVOIDANCE MODEL OF DRIVER BEHAVIOUR

Thus far a simple representation of behavioural aspects of avoidance responding in driving has been presented and discussed. Below, this representation is extended to make explicit a number of covert variables which it has been suggested may mediate relationships between stimuli and responses in that schema. The extended representation may be described as a threat-avoidance model of driver behaviour and includes some indication of the potentially relatively complex origins of many discriminative stimuli, representation of driver expectations, and information processing and makes more explicit how the affective state of the driver might mediate a shift from a competing or nonavoidance response to a delayed avoidance response. Furthermore, in its developed form the model encompasses those situations in which a potential aversive stimulus may occur without any preceding discriminative stimulus.

The proposed threat-avoidance model is presented schematically in Figure 2. It should be noted that in this model the term "threat" has been used in place of the earlier, more unwieldy term "potential aversive stimulus" but is intended to mean precisely the same thing.

Comparing Figure 2 with Figure 1, one salient addition is that the discriminative stimulus for a potential aversive stimulus or threat (box a, Figure 2) is seen to arise out of an integration of the driver's perception of his speed, the road environment in his intended path, and his ongoing capability (circles s, t, u at top of Figure 2), an integration which may alternatively lead to no discriminative stimulus (box h). Each of these stimulus situations may be associated with some degree of expectation in the driver of threat (circle v) or no threat (circle x) respectively.

Where impairment in perceived capability (circle t) is a primary factor underlying the discriminative stimulus, an anticipatory avoidance response might consist of raising the level of performance and other compensatory responses. Such adjustments have been suggested by Näätänen and Summala (op. cit., pp. 113, 115, 139-143, 148, 152-3) and have been observed in truck

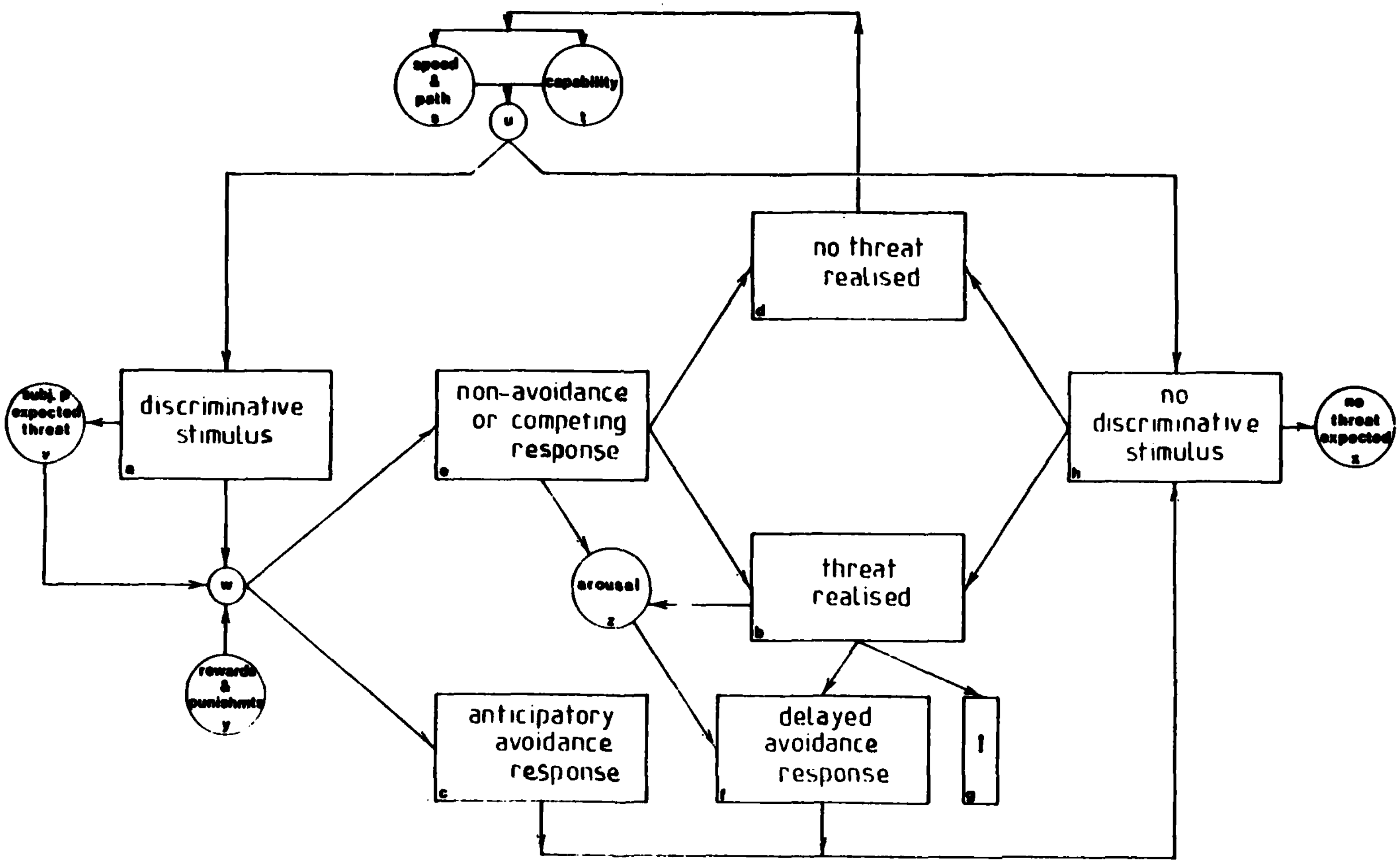

Figure 2. Threat-avoidance model of driver behaviour.

drivers under various conditions of prolonged convoy driving (Fuller, 1981, 1983). It should be noted that a driver's anticipatory avoidance response may be inadequate (path from box c to h to b), thus leading to a delayed avoidance response (box f). Furthermore, one can conceive of a feedback loop (not shown in Figure 2) from box c to circles s and t representing the relationship between events when the driver is unsure of the effectiveness of his anticipatory avoidance response, a condition especially likely to occur in the learner driver.

Given that a discriminative stimulus arises (as the output from circle u) the probability of an anticipatory avoidance or a nonavoidance response is partly determined by the driver's subjective probability of expected threat (circle v) and partly by the rewards and punishments for the various response alternatives (circle y), the integration of these being represented by circle w. If, on the other hand, the output from circle u is no discriminative stimulus (box h) for a threat and its associated expectation (circle x), one of two events may follow. Either no threat is realised, in which case the expectation is correct (path from box h to box d) or a threat occurs (path from box h to box b) and so a delayed avoidance response is demanded of the driver to avoid an accident (path from box b to box f). This last series of events might arise because of factors such as (1) incorrect output from the initial integration of information (circle u) due primarily to perceptual error on the part of the driver (e.g., lapses in vigilance, attention to inappropriate stimuli); (2) inadequate learning of the relationship between threats and their precursors; (3) unpredictable behaviour of other road users (see Wilde, 1976); or (4) sudden mechanical failure.

Turning now to the situation where the driver makes no anticipatory avoidance response to a discriminative stimulus (box e), as mentioned earlier the approach of a threatening stimulus may elicit increases in arousal (path from box b to circle z) which may become aversive and which in turn may motivate a delayed avoidance response, perhaps earlier than would otherwise have been the case. In such circumstances the response is strictly one of <u>escape</u> from an aversive stimulus, rather than avoidance, because onset of the aversive stimulus has occurred.

Another possibility is that the act of making no anticipatory avoidance response or a competing response may itself elicit heightened arousal, particularly under conditions in which the driver has a high subjective probability of expected threat (path from box e to circle z). It may well be that in these circumstances drivers become aware of feelings of risk. Taylor (1981) has suggested that high arousal may not only be a component of risk but also induce such feelings.

Should increases in arousal become aversive, again a delayed avoidance response may be motivated, as in the previous example, but in this case even before the expected threat is realised. Such delayed avoidance or escape responses would be rewarded by reductions in aversive high arousal, experienced as decreases in feelings of anxiety, fear, tension, and so on. It is interesting to note that in his earlier work Taylor (1964) equated feelings of "subjective risk" with "anxiety level," defining them operationally in terms of subjects' mean GSR rate. On the basis of his experimental evidence, he concluded that drivers adopt a level of risk or anxiety they wish to experience and drive so as to maintain it, a concept, as indicated earlier, very similar to Wilde's notion of target level of risk.

The arousal concept as employed here is intended to include possible cortical, somatic, and autonomic expressions of activation. As suggested in the section on discriminative and potential aversive stimuli above, in response to expected or actual threat, increases in arousal are within limits adaptive, facilitating information processing and responding. Also within limits, increases in arousal may be intrinsically rewarding (Berlyne, 1969), independently of any rewarding affects mediated through improvements in performance. This implies that drivers may opt for nonavoidance or competing responses in order to boost arousal to a rewarding level (or maintain it if declining). This feature may be particularly characteristic of the more extraverted driver (Eysenck, 1965) and may in part explain his slightly higher involvement in traffic and violations. Relatively large increases in arousal, however, as well as being aversive rather than rewarding, may also have the effect of inhibiting cognitive aspects of performance (see Broadbent, 1971) and facilitating stereotyped responding, both of which may be maladaptive.

Tranquillisers and depressant drugs (e.g., alcohol), in addition to states of drowsiness, may well suppress emotional responses to particular road situations which normally mediate delayed avoidance or escape responses by the driver. Furthermore, if the driver is angry or excited because of situations independent of the driving task, he may misattribute road situation-induced arousal to his general emotional state and again fail to make habitual avoidance responses. This may be a mechanism which in part mediates the relationship between aggressivity and involvement in road accidents, a relationship well-documented by Näätänen and Summala (op. cit., pp. 41-68). It might be added here also that drivers may well display feelings of aggression toward other road users by intentionally delaying avoidance responses, thereby constituting a threat to others and requiring them to make compensatory adjustments instead.

INDIVIDUAL DIFFERENCES IN DRIVING

One speculation which arises from the threat-avoidance model proposed here is that there may be drivers who are predominantly delayed avoidance responders. It is also worth considering that perhaps at different times one kind of response may predominate in the same driver. Possible differences associated with these two types of responding are listed in Table 1, which is presented entirely speculatively, although groups of drivers have been identified who are relatively poor at detecting hazards (Quenault, 1967) and who tend to detect them late or underestimate them (Quimby and Watts, 1981). Such drivers might well fit into a delayed avoidance group.

IMPLICATIONS FOR ROAD SAFETY MEASURES

The threat-avoidance model has a number of implications for where interventions might lead to improvements in road safety. Suggested areas for intervention include the following:

Table 1

Two Types of Driving: Anticipatory and Delayed Avoidance

Anticipatory avoidance driving	Delayed avoidance driving
Preadaptive	Adaptive
Slower speed approaching hazards	Faster speed approaching hazards
Control actions unhurried	Control actions hurried
Low arousal in driving	High arousal in driving
Does not tolerate high risk	Tolerates high risk
Low accident involvement	High accident involvement
More introverted	More extraverted
Susceptible to factors mainly affecting cognitive functioning	Susceptible to factors mainly affecting emotional functioning
Sensitive to cognitive approaches in road safety propaganda	Sensitive to emotional approaches in road safety propaganda

(1) Facilitation of maintenance of, and improvement in, driver performance capability, e.g., by avoidance of certain drugs, avoidance of conditions of very low and very high arousal.

(2) Removal of potential aversive stimuli in the road environment, e.g., by physical separation of different classes of road user, highway modifications, enforcement of safe driving rules, enforcement of speed controls.

(3) Facilitation of learning of correct expectations (i.e., correct identification of discriminative stimuli), e.g., through educating road users in "reading" the road scene, making potential hazards more obvious (see Brown, 1980, and McKenna, 1982, who advocate an equivalent strategy). The systematic use of hazard warning signs where appropriate should in theory enable anticipatory avoidance responses to be made to the signs rather than to the driver's own judgment about possible potential aversive stimuli and in the simplest case the signs may come to elicit CARs. Such responses may be strengthened if the sign also elicits an aversive emotional response which is reduced by making the avoidance response. Encouraging drivers to fantasise hazards in particular road situations (e.g., approaching a blind corner) may facilitate this process.

(4) Manipulation of rewards and punishments to reinforce anticipatory rather than delayed avoidance responding. Such a behavioural approach to the development of road safety measures has long been supported by, for example, Wilde (see Wilde, 1981, and Wilde and Murdoch, 1982), who has argued for decreasing the utility to the driver of risky behaviour (i.e., making competing and delayed avoidance responses less rewarding) and increasing the utility of cautious behaviour (i.e., making anticipatory avoidance responses more rewarding).

(5) Facilitation of effectiveness of both anticipatory and delayed avoidance responding, e.g., through driver training in vehicle control, improvements in safe handling characteristics of vehicles. Brown (1980) has similarly identified this area as one of potential useful intervention and has suggested practice in the use of error correction procedures.

(6) Avoidance of factors which tend to make drivers insensitive to arousal increases caused by their interactions with the road environment, e.g., through driver education about errors of attribution and the effects of certain drugs.

COMPARISON OF MODELS

The threat-avoidance model clearly identifies a much wider range of areas of intervention with potential to improve road safety than does Wilde's Theory of Risk Homeostasis which is confined essentially to type (4) interventions described above. In addition, the proposed model differs from that of Wilde and that of Näätänen and Summala in two important ways.

The first major difference is in the use of the concept of subjective risk. In both the Wilde and Näätänen and Summala models, subjective risk of an act refers to the subjective probability of a consequential accident. Näätänen and Summala also include arrest as a consequence and in addition use the word risk to refer to the correlated <u>experience</u> of fear (e.g., op. cit., p. 79). However, it is the subjective probability of accident or arrest that is argued to be crucial in driver decision making. This concept of risk has been criticised by McKenna (1982), who argues against the presupposition that drivers are capable of monitoring the probabilities of what are extremely infrequent events. In the currently proposed threat-avoidance model, it is suggested that subjective probabilities refer not to accidents as such but to the likelihood of some <u>potential</u> aversive stimulus or threat regarding which some avoidance response may have to be made sooner or later. It is also suggested that the <u>experience</u> of risk (i.e., feelings of fear, anxiety, etc.) may arise when the driver becomes aware of a dissociation between his actual response and the appropriate anticipatory avoidance response and also when a potential aversive stimulus becomes more imminent (i.e., the more an avoidance response is delayed).

The second major difference between the models under discussion is concerned with basic conceptualisations of driver motivation. In essence, Näätänen and Summala argue that drivers opt for zero risk (of accident or arrest) in their preferred responding and are only objectively risky because various factors raise the threshold at which risk is experienced. Wilde argues on the other hand that drivers seek to maintain a target level of risk which is greater than zero and which may be raised by various factors. The threat-avoidance model presupposes that drivers opt for zero risk of accident (i.e., it assumes that such events are always aversive) but that drivers may make anticipatory avoidance, competing, or delayed avoidance responses depending in part on the rewards and punishments associated with each kind of response, the accuracy with which discriminative stimuli are recognised, the subjective probability of a potential aversive stimulus, the effectiveness of avoidance responses when made, their arousal condition, and in part on the occurrence of unpredictable events. From an objective point of view it is suggested that in the presence of a threat the more delayed an avoidance response the greater is the risk of accident. However, this concept of "risk of accident" is not a motivating variable and as suggested above a host of factors may mediate delays in avoidance responding.

Finally, it may be suggested that it is possible to subsume the motivational components of at least the Näätänen and Summala model under the model currently proposed. Referring back to Figure 2, presumably the typical Näätänen and Summala driver would follow the path from circle w (integration) to box c (anticipatory avoidance), thereby minimising risk of accident (and incidentally experiencing no risk in the sense of fear). Such a driver would only become objectively risky when factors affected the adequacy with which discriminative stimuli were recognised. On the other hand, the typical Wilde driver would presumably follow the path from circle w to box e (nonavoidance or competing response), intentionally delaying an avoidance response as far as the point where a target level of subjective risk of accident was reached. Since this last concept is not part of the current model, it is of course not represented there, but it is tempting to translate "subjective risk" into "anxiety level" (see Taylor, 1964) and regard Wilde's target level of risk as some threshold of aversive arousal which when exceeded motivates drivers to make delayed avoidance responses and thereby bring subjective risk back down to target level.

In conclusion, it should perhaps be emphasised that in accounting for driver motivation the threat-avoidance model does not require drivers to be sensitive to accident possibilities, nor to necessarily opt for potentially more aversive than less aversive consequences, nor to have an inevitable dissociation between subjective and objective risk. It is based essentially on a conceptualisation of the driving task as involving learned avoidance responses to potential aversive stimuli and an application of well-established principles of behaviour to the driving situation.

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SUMMARY

A behavioural analysis of the driving task is presented, arising out of a brief review of the motivational dimensions of Wilde's (1981) Theory of Risk Homeostasis and the Zero Risk Model of Driver Behaviour proposed by Näätänen and Summala (1976). The analysis is developed into a threat-avoidance model of driver behaviour and suggests that, when confronted with a discriminative stimulus for a potential aversive event, what a driver does depends in particular on the rewards and punishments for alternative responses. Implications of the model for the learner driver, road safety measures, and earlier conceptualisations of driver motivation are discussed.

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APPENDIX I

TIME HEADWAY IN DIFFERENT VEHICLE-FOLLOWING MANOEUVRES[1]

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Summary.--Reliable differences in time headway were observed for 6 experienced volunteer truck drivers who drove continuously 11 hr. on each of 4 days over a 300-mile route. Type of manoeuvre was a significant factor in observed time headway in following another vehicle.

In a traffic situation where one vehicle is following another, time headway is the time it would take the following vehicle to reach the leading vehicle if the latter stopped dead. An initial study of vehicle following by truck drivers (Fuller, 1979; McDonald, 1978) explored amongst other variables the effects of prolonged driving on time headway. But one problem recognized in that work was that time headway may be determined by demands of aspects of the traffic and road environment other than the leading vehicle and the driver's following strategy, for example, his anticipation of oncoming obstructions, junctions, pedestrian crossings, bends, bridges, ascents, descents and deteriorations in the road surface or in visibility. A further factor might also be the driver's efforts to facilitate the safe passing of overtaking vehicles. These features of the road and traffic environment clearly complicate interpretation of gross following data. The present study involved a preliminary attempt to overcome the problem by classifying each following observation as one of four discrete following manoeuvres: steady state following (vehicles maintaining relatively constant time headway in a 'coupled' state), closing (reducing distance to leading vehicle), prior-to-overtaking and braking (following vehicle brakes applied).

The experimental design replicated the late shift of the earlier study with the modification that a second vehicle was used at intervals as a leading vehicle to create occasional following situations for the driver of the experimental truck. Subjects were 6 volunteer professional truck drivers, each paid $160 for participating in the project. They were required to drive an instrumented 7-ton Bedford rigid van-type truck for 11 hr. from 15.00 hr. to 02.30 hr. on each of four consecutive days over a preselected route of approximately 300 miles. Driving was continuous except for a 30-min. meal break after 5.5 hr. and a 10-min. break during each 5.5-hr. period. Time

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headway for all following episodes was continuously recorded, sampled, and analysed as described in Fuller et al. (1978).

Means and standard deviations for time headway in seconds for each type of following manoeuvre were as follows: steady state 1.66 (0.20), closing 2.08 (0.34), prior-to-overtaking 0.93 (0.12) and braking 2.86 (0.43). The data were submitted to a single-factor, repeated-measures analysis of variance which yielded a significant $\underline{F}$ for following manoeuvre ($\underline{F}(3,15) = 130.67$, $\underline{p} < .01$). Tukey's HSD test (HSD = 0.37, $\underline{p} < .01$) indicated that comparisons between all pairs of means were significant at the 1% level.

From the point of view of driving safety these results provide an indication of circumstances in which time headway is particularly short. Not surprisingly this measure is shortest immediately prior to overtaking a leading vehicle (0.93 sec.) but even in steady state following (1.66 sec.) is still less than the recommended minimum interval of 2 sec. On the other hand, when braking, positive deceleration relative to the leading vehicle was observed with drivers actually increasing time headway to a safe margin (2.86 sec.). This demonstration of reliable differences implies that type of following manoeuvre should clearly be taken into account in interpreting studies of vehicle following as well as in exploring the effects of different independent variables on following performance.

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